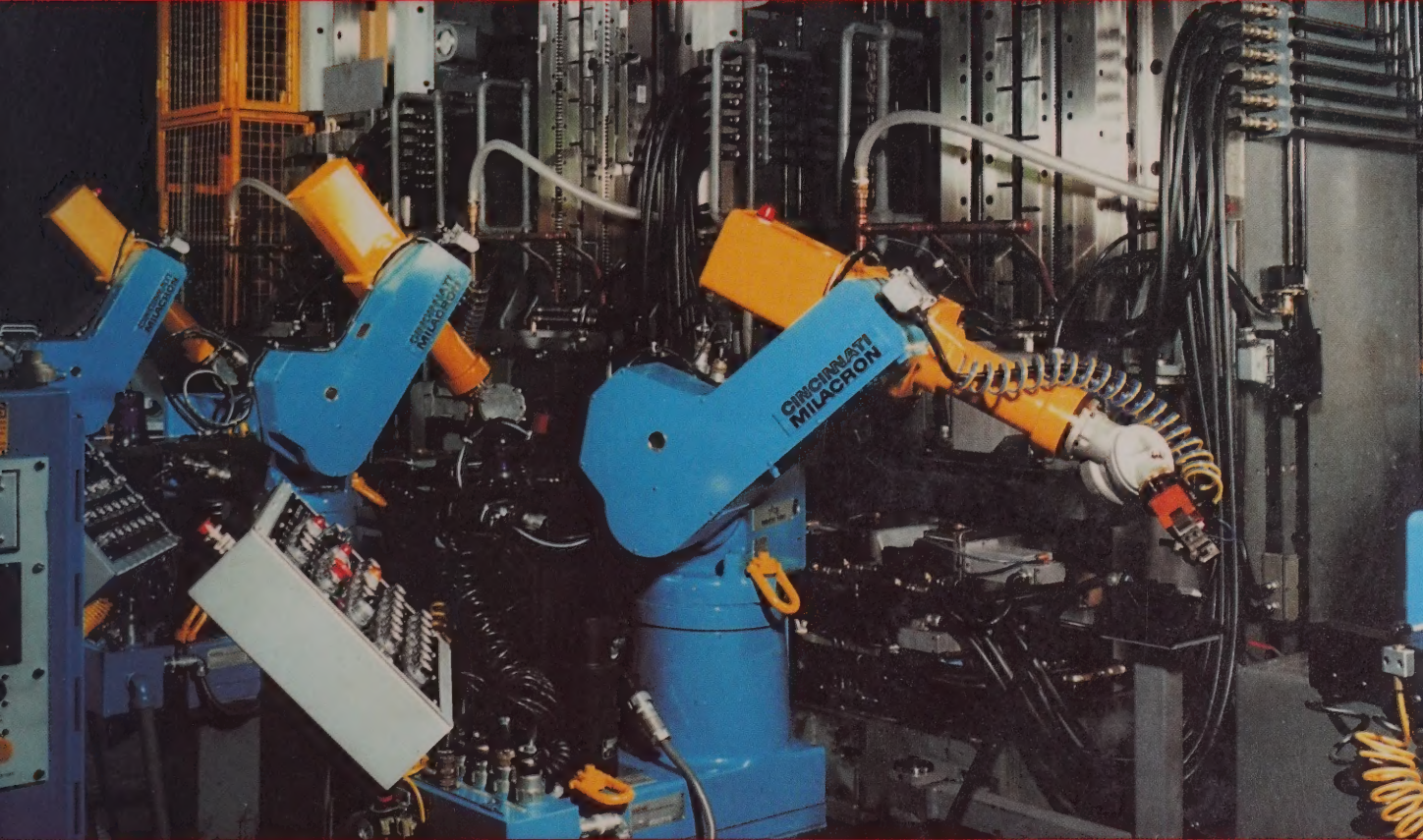


ELECTRIC MOTOR CONTROL



Fourth Edition

***Walter N.
Alerich***



ELECTRIC MOTOR CONTROL

ELECTRIC MOTOR CONTROL

FOURTH EDITION

Walter N. Alerich



DELMAR PUBLISHERS INC.®

NOTICE TO READER

Publisher does not warrant or guarantee any of the products described herein or perform any independent analysis in connection with any of the product information contained herein. Publisher does not assume, and expressly disclaims, any obligation to obtain and include information other than that provided to it by the manufacturer.

The reader is expressly warned to consider and adopt all safety precautions that might be indicated by the activities described herein and to avoid all potential hazards. By following the instructions contained herein, the reader willingly assumes all risks in connection with such instructions.

The publisher makes no representations or warranties of any kind, including but not limited to, the warranties of fitness for particular purpose or merchantability, nor are any such representations implied with respect to the material set forth herein, and the publisher takes no responsibility with respect to such material. The publisher shall not be liable for any special, consequential or exemplary damages resulting, in whole or in part, from the readers' use of, or reliance upon, this material.

Cover photos: Top photo courtesy of Cincinnati Milacron. Safety equipment may have been removed or opened to clearly illustrate products and must be in place prior to operation.

Bottom photo courtesy of GE Fanuc Automation North America, Inc.

Delmar Staff

Associate Editor: Marjorie A. Bruce

Assistant Managing Editor: Gerry East

Production Editor: Mary Ormsbee

Design Coordinator: Susan Mathews

For information, address Delmar Publishers Inc.,
2 Computer Drive West, Box 15-015
Albany, New York 12212-5015

COPYRIGHT © 1988
BY DELMAR PUBLISHERS INC.

All rights reserved. No part of this work covered by the copyright hereon may be reproduced or used in any form or by any means—graphic, electronic, or mechanical, including photocopying, recording, taping, or information storage and retrieval systems—without written permission of the publisher.

Printed in the United States of America
Published simultaneously in Canada
by Nelson Canada,
A Division of International Thomson Limited

10 9 8 7 6 5 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Alerich, Walter N.
Electric motor control.

Includes index.

1. Electric controllers. 2. Electric motors.

I. Title.

TK2851.A48 1988 621.46'2 88-6998

ISBN 0-8273-3039-1 (pbk.)

ISBN 0-8273-3040-5 (instructor's guide)

CONTENTS

PREFACE *xi*

SECTION 1 INTRODUCTION

1

- UNIT 1 General Principles of Electric Motor Control 2
- UNIT 2 Fractional and Integral Horsepower Manual Motor Starters 17
- UNIT 3 Magnetic Line Voltage Starters 24

SECTION 2 CIRCUIT LAYOUT, CONNECTIONS AND SYMBOLS

45

- UNIT 4 Symbols 46
- UNIT 5 Interpretation and Application of Simple Wiring and Elementary Diagrams 51

SECTION 3 CONTROL PILOT DEVICES

67

- UNIT 6 Push Buttons and Control Stations 68
- UNIT 7 Relays and Contactors 74
- UNIT 8 Timing Relays 84
- UNIT 9 Pressure Switches and Regulators 95
- UNIT 10 Float Switches 97
- UNIT 11 Flow Switches 99
- UNIT 12 Limit Switches and Proximity Control 102
- UNIT 13 Phase Failure Relays 106
- UNIT 14 Solenoid Valves 108
- UNIT 15 Temperature Switches 111

SECTION 4 BASIC CONTROL CIRCUITS

113

- UNIT 16 Two-wire Controls 114
- UNIT 17 Three-wire and Separate Controls 116
- UNIT 18 Hand-off Automatic Controls 120
- UNIT 19 Multiple Push-button Stations 123
- UNIT 20 Interlocking Methods for Reversing Control 125
- UNIT 21 Sequence Control 132
- UNIT 22 Time-delay, Low-voltage Release Relay 137

SECTION 5 AC REDUCED VOLTAGE STARTERS

141

UNIT 23	The Motor and Starting Methods	142
UNIT 24	Primary Resistor-type Starters	148
UNIT 25	Autotransformer Starters	153
UNIT 26	Part Winding Motor Starters	157
UNIT 27	Automatic Starters for Star-Delta Motors	161
UNIT 28	AC Solid-State Reduced Voltage Controller	167

SECTION 6 THREE-PHASE, MULTISPEED CONTROLLERS

175

UNIT 29	Controllers for Two-speed, Two-winding (Separate Winding) Motors	176
UNIT 30	Two-speed, One-winding (Consequent Pole) Motor Controller	180
UNIT 31	Four-speed, Two-winding (Consequent Pole) Motor Controller	186

SECTION 7 WOUND ROTOR (SLIP RING) MOTOR CONTROLLERS

191

UNIT 32	Wound Rotor Motors and Manual Speed Control	192
UNIT 33	Push-button Speed Selection	196
UNIT 34	Automatic Acceleration for Wound Rotor Motors	199
UNIT 35	Automatic Speed Control for Wound Rotor Motors	204
UNIT 36	Solid-State Adjustable Speed Controller for AC Wound Rotor Motors	207

SECTION 8 SYNCHRONOUS MOTOR CONTROLS

211

UNIT 37	Synchronous Motor Operation	212
UNIT 38	Push-button Synchronizing	217
UNIT 39	Timed Semiautomatic Synchronizing	220
UNIT 40	Synchronous Automatic Motor Starter	222

SECTION 9 DIRECT-CURRENT CONTROLLERS

231

UNIT 41	About DC Motors	232
UNIT 42	Across-the-line Starting	236
UNIT 43	Use of Series Starting Resistance	238
UNIT 44	Manual Faceplate Starters	241
UNIT 45	Compensating and Definite Time Control Starting	245
UNIT 46	Solid-State Adjustable Speed Control	250

SECTION 10 METHODS OF DECELERATION

257

UNIT 47	Jogging (inching) Control Circuits	258
UNIT 48	Plugging	262
UNIT 49	Electric Brakes	270
UNIT 50	Dynamic and Regenerative Braking	274
UNIT 51	Electric and Electronic Braking	280

SECTION 11 MOTOR DRIVES

285

UNIT 52	Direct Drives and Pulley Drives	286
UNIT 53	Gear Motors	291
UNIT 54	Variable Frequency Mechanical Drives	294
UNIT 55	AC Adjustable Frequency Solid-State Drives	297
UNIT 56	Magnetic Clutch and Magnetic Drive	301
UNIT 57	DC Variable Speed Control—Motor Drives	306
UNIT 58	Programmable and Motion Control	310
UNIT 59	Motor Startup and Troubleshooting Basics	320

APPENDIX A	Motor Types and Line Diagrams	332
------------	-------------------------------	-----

APPENDIX B	Power Supplies and Circuits	334
------------	-----------------------------	-----

GLOSSARY	336
----------	-----

INDEX	343
-------	-----



Digitized by the Internet Archive
in 2026 with funding from
Amateur Radio Digital Communications, Grant 151

<https://archive.org/details/electronicmotorc00unse>

INDEX OF TABLES

TABLE 3-1	Standard Motor Starter Sizes and Ratings	38
TABLE 5-1	Control and Power Connections—600 Volts or Less— Across-the-Line Starters	56
TABLE 5-2	Sample Nameplates and Connection Diagrams	60
TABLE 8-1	Standard Elementary Diagram Symbols for Timed Contacts	87
TABLE 21-1	Functions and Their Associated Devices	134
TABLE 46-1	DC Drive Speed Control	251
TABLE 59-1	Industrial Controls Index to Troubleshooting Suggestions	324
TABLE 59-2	Industrial Control Troubleshooting Tips	326

PREFACE

The fourth edition of *Electric Motor Control* updates a text long-regarded as one of the standard references for the study of motor control theory and applications. The rapidly changing state of the technology requires technicians who are familiar with the latest equipment, components, circuitry and applications. *Electric Motor Control* provides this information in a clear, well-illustrated format.

INTRODUCTION

Electric motors provide one of the principal sources for power for driving machine tools and other industrial equipment. In most cases, the motor is included as an integral part of the design of the machine. Related to this is the design, construction, installation, and maintenance of equipment to control the motor.

The phrase *motor control* refers to the functions available from a motor controller as applied to a motor, such as speed control, reversal, acceleration, deceleration, starting, and stopping. This new edition emphasizes solid-state control of these functions.

Various texts, handbooks, and manufacturers' manuals describe different types of controllers. However, it is often difficult to find a single source for this information. *Electric Motor Control* serves as a source of technical and practical information for students, instructors, apprentices, journeyman electricians, technicians, engineers, electrical contractors, and others. A thorough study of this text will contribute to an understanding of the theory, operation, installation, and maintenance of motor controllers.

The goal in all areas of industry is increased production and decreased costs through automation. Design, maintenance, and operation of the control systems for automated equipment creates the need for a thorough knowledge of motor control basics.

Electric Motor Control is especially helpful to construction electricians and apprentices for installing and operating control systems, to plant maintenance personnel for maintaining the operation of production machines, and to drafters and designers of motor control systems. It is used extensively in apprentice training programs, journeyman training, vocational-technical schools, and two-year colleges. A working knowledge of direct- and alternating-current fundamentals and direct- and alternating-current motor theory and operation, or equivalent experience, is a prerequisite to the study of this text.

Once the electrician is on the job, this text, in conjunction with the *National Electrical Code*®, serves as a quick reference handbook for both new construction and maintenance.

The text is written in easy-to-understand language. Each unit covers a concise topic. Expected student learning is outlined in the objectives at the beginning of each unit. Learning is tested through the Study/Discussion/Test Questions at the end of each unit. The Appendix and Glossary provide further explanation of terms and servicing or troubleshooting aids.

MAJOR CONTENT CHANGES FOR THE FOURTH EDITION

- Color has been added to the text to highlight important concepts.
- The units on circuit layouts, connections, and symbols were moved forward in the text so that students will have the necessary preparation to read circuit schematic diagrams in the following units.
- Unit 7, Relays and Contactors, has added solid-state relays and surge protection for solid-state devices used with magnetic switches.
- Unit 8, Timing Relays, has added electronic timers.
- Unit 12, Limit Switches, has added solid-state proximity switches, including operation and applications.
- Unit 13, Phase Failure Relays, has added solid-state, large motor current monitor.
- Unit 15, Temperature Switches, has added solid-state temperature control systems.
- Unit 21, Sequence Control, has added solid-state logic elements and control functions (AND and OR functions).
- NEW Unit 28, AC Solid-State Reduced Voltage Controller, covers solid-state control, reduced voltage control systems, solid-state control used with existing magnetic devices, noise suppression, and applications of controllers.
- NEW Unit 36, Solid-State Adjustable Speed Controller for AC Wound Rotor Motors, covers power factor correction.
- Unit 40, Synchronous Automatic Motor Starter, has added brushless solid-state motor excitation.
- Unit 45, Compensating and Definite Time Control Starting, has added definite time control starting.
- NEW Unit 46, Solid-State Adjustable Speed Control, covers power conversion and control, starting the motor, DC adjustable speed control (single-phase AC), and DC adjustable speed control (three-phase).
- Unit 50, Dynamic Braking, has added regenerative braking.
- Unit 51, Electric Braking, has added electronic braking.
- NEW Unit 55, AC Adjustable Frequency Solid-State Devices, covers solid-state control of AC motors, functions of converters and inverters, and features of adjustable frequency drives.
- NEW Unit 58, Programmable and Motion Control, covers components of a programmable control and their functions, installation of controllers, motor control centers, and motion control with stepper motors.

ABOUT THE AUTHOR

Walter N. Alerich, B.V.E., M.A., has an extensive background in the electrical trades. As a journeyman wireman, he has had years of experience in the practical applications of motor control. As a teacher, supervisor, and administrator, Mr. Alerich spent many years in education and is aware of the need for effective instruction in this field. A former department head of the Electrical-Mechanical Department, Los Angeles Trade-Technical College, he has written extensively on the subject of electricity and motor controls. He currently serves as an international specialist and consultant in the field of electrical trades, developing curriculum and training programs, certifying crafts people, and designing training facilities.

ACKNOWLEDGMENTS

The author expresses appreciation to the officers and members of the International Brotherhood of Electrical Workers, No. 11, and the National Electrical Contractors Association in Los Angeles, who were most helpful in constructive guidance, as were the members of the California State Curriculum Committee for Electrical Trades.

The author and staff at Delmar Publishers wish to express their appreciation to the instructors who reviewed the manuscript and made many constructive suggestions for improvements:

B.J. Hodges, Caldwell Community College and Technical Institute, Hudson, NC
28638

Robert H. Arnold, Griffen Technical Institute, Griffen, GA 30223

John Wiczerza, Macomb County Community College, Warren, MI 48090

and to the following instructors for their recommendations for the revision:

Ben Harris, Holland Community Educational Center, Holland, MI 49423

Carl Locke, Willard J. Graff Area Vocational Technical Center, Springfield, MO
65802

Harry Curriden, Lyons Institute, Philadelphia, PA 19134

Shawn Redding, Wilkes Community College, Wilkesboro, NC 28697

Ronald G. Oswald, Dean Institute of Technology, Pittsburgh, PA 15226

C.B. Hahn, Aiken Technical College, Aiken, SC 29801

George Bulen, Navarro College, Corsicana, TX 75110

The author also wishes to thank the Los Angeles Trade-Technical College and the following companies for providing illustrations and technical information for this text:

Allen-Bradley Co.

Ambi-Tech Industries, Inc.

Automatic Switch Co.

Eagle Signal Controls

Eaton Corporation, Cutler-Hammer Products

Electric Machinery Manufacturing Co.

Furnas Electric Co.

General Electric Co.

Gould Inc.

Magnecraft Electric Company

McDonnell and Miller, ITT

Micro Switch, a Honeywell Division

Reliance Electric Co.

Square D Co.

Sterling Electric Inc.

U.S. Electrical Motors

Ward Leonard Electric Co., Inc.

Warner Electric Brake and Clutch Co.

Westinghouse Electric Corporation

SECTION ONE

A series of ten thin, horizontal white lines stacked vertically, serving as a decorative separator between the section title and the main title.

INTRODUCTION

- UNIT 1** General Principles of Electric Motor Control
- UNIT 2** Fractional and Integral Horsepower Manual Motor Starters
- UNIT 3** Magnetic Line Voltage Starters

UNIT 1 *General Principles of Electric Motor Control*

Objectives After studying this unit, the student will be able to:

- State the purpose and general principles of electric motor control
- State the difference between manual and remote control
- List the conditions of starting and stopping, speed control, and protection of electric motors
- Explain the difference between compensating and definite time delay action

There are certain conditions that must be considered when selecting, designing, installing, or maintaining electric motor control equipment. The general principles are discussed to help understanding and to motivate students by simplifying the subject of electric motor control.

Motor control was a simple problem when motors were used to drive a common line shaft to which several machines were connected. It was simply necessary to start and stop the motor a few times a day. However, with individual drive, the motor is now almost an integral part of the machine and it is necessary to design the motor controller to fit the needs of the machine to which it is connected. Large installations and the problems of starting motors in these situations may be observed in figures 1-1 and 1-2.

Motor control is a broad term that means anything from a simple toggle switch to a complex system with components such as relays, timers, and switches. The common function of all controls, however, is to control the operation of an electric motor. As a result, when motor control equipment is selected and installed, many factors must be considered to insure that

the control will function properly for the motor and the machine for which it is selected.

MOTOR CONTROL INSTALLATION CONSIDERATIONS

When choosing a specific device for a particular application, it is important to remember that the motor, machine, and motor controller are interrelated and need to be considered as a package. In general, five basic factors influence the selection and installation of a controller.

1. ELECTRICAL SERVICE

Establish whether the service is direct (dc) or alternating current (ac). If ac, determine the frequency (hertz) and number of phases in addition to the voltage.

2. MOTOR

The motor should be matched to the electrical service, and correctly sized for the machine load in horsepower rating (hp). Other considerations include motor speed and torque. To select proper protection for

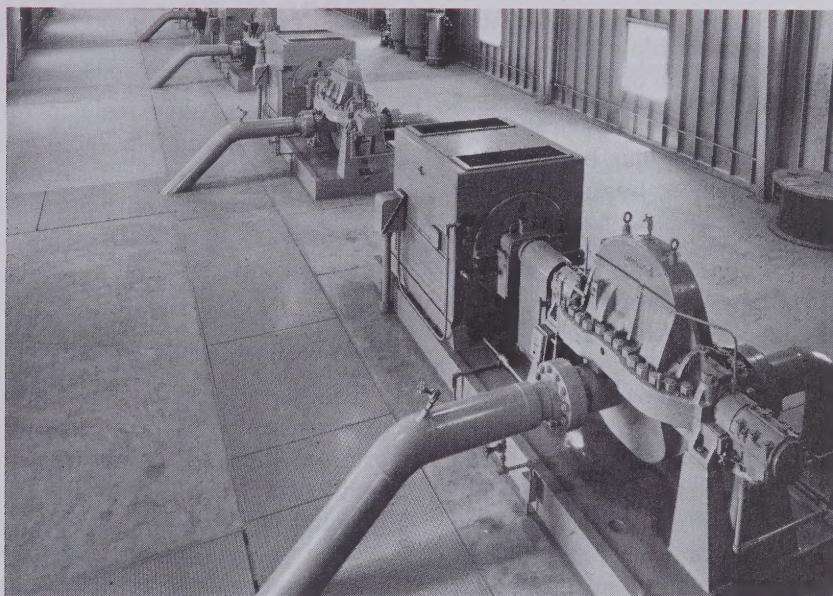


FIG. 1-1 Five 2000-hp, 1800-rpm induction motors driving water pumps for a Texas oil/water flood operation. Pumps are used to force water into the ground and "float" oil upward. (Courtesy Electric Machinery Mfg. Co.)

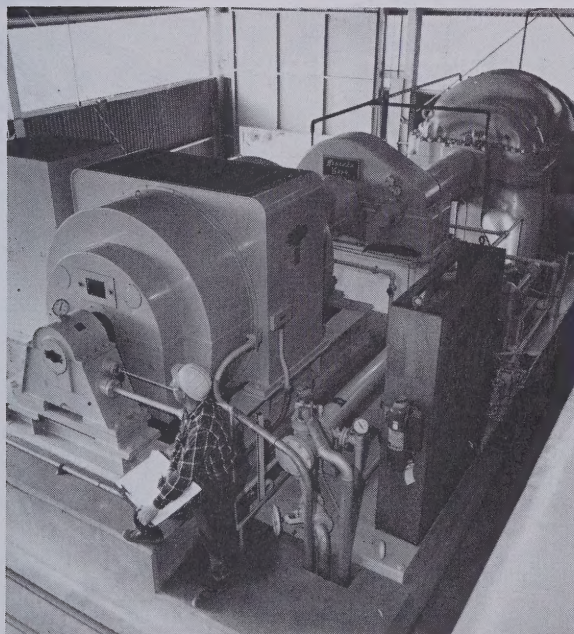


FIG. 1-2 Horizontal 4000-hp synchronous motor driving a large centrifugal air compressor (Courtesy Electric Machinery Mfg. Co.)

the motor, its full load current rating (FLC), service factor (SF), time rating (duty), and other pertinent data — as shown on the motor nameplate — must be used.

3. OPERATING CHARACTERISTICS OF CONTROLLER

The fundamental tasks of a motor controller are to start and stop the motor, and to protect the motor, machine, product and operator. The controller may also be called upon to provide supplementary functions such as reversing, jogging or inching, plugging, operating at several speeds or at reduced levels of current and motor torque. (See Appendix, glossary of terms).

4. ENVIRONMENT

Controller enclosures serve to provide safety protection for operating personnel by preventing accidental contact with live parts. In certain applications, the controller itself must be protected from a variety of environmental conditions which might include:

- Water, rain, snow or sleet
- Dirt or noncombustible dust
- Cutting oils, coolants or lubricants

Both personnel and property require protection in environments made hazardous by the presence of explosive gases or combustible dusts.

5. ELECTRICAL CODES AND STANDARDS

Motor control equipment is designed to meet the provisions of the National Electrical Code (NEC). Also, local code requirements must be considered and met when installing motors and control devices. Presently, code sections applying to motors, motor circuits, and controllers and industrial control devices are found in Article 430 on motors and motor controllers, Article 440 on air conditioning and refrigeration equipment, and Article 500 on hazardous locations of the National Code.

The 1970 Occupational Safety and Health Act (OSHA) as amended, requires that each employer furnish employment in an environment free from recognized hazards likely to cause serious harm.

Standards established by the National Electrical Manufacturers Association (NEMA) assist users in the proper selection of control equipment. NEMA standards provide practical information concerning the construction, testing, performance, and manufacture of motor control devices such as starters, relays and contactors.

One of the organizations which actually test for conformity to national codes and standards is Underwriters' Laboratories (UL). Equipment that is tested and approved by UL is listed in an annual publication, which is kept current by means of bimonthly supplements to reflect the latest additions and deletions. A UL listing does not mean that a product is approved by the NEC. It must be acceptable to the local authority having jurisdiction.

PURPOSE OF CONTROLLER

Some of the complicated and precise automatic applications of electrical control are illustrated in figures 1-3 and 1-8. Factors to be considered when selecting and installing motor control components for use with particular machines or systems are described in the following paragraphs.

Starting

The motor may be started by connecting it directly across the source of voltage. Slow and gradual starting may be required, not only to protect the machine, but also to insure that the line current inrush on starting is not too great for the power company's system. Some driven machines may be damaged if they are started with a sudden turning effort. The frequency of

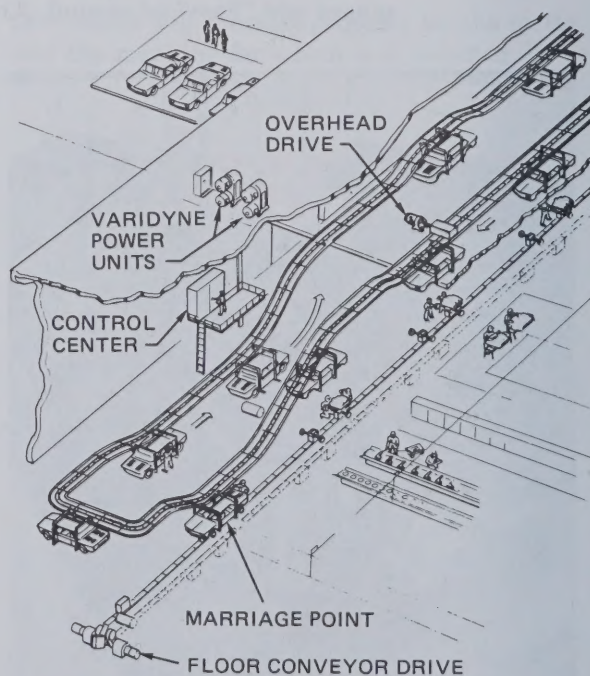


FIG. 1-3 Synchronizing two automobile assembly systems (Courtesy U.S. Electrical Motors)

starting a motor is another factor affecting the controller. A combination fused disconnect switch and motor starter is shown in figure 1-4.

Stopping

Most controllers allow motors to coast to a standstill. Some impose braking action when the machine must stop quickly. Quick stopping is a vital function of the controller for emergency stops. Controllers assist the stopping action by retarding centrifugal motion of machines and lowering operations of crane hoists.

Reversing

Controllers are required to change the direction of rotation of machines automatically or at the command of an operator at a control station. The reversing action of a controller is a continual process in many industrial applications.

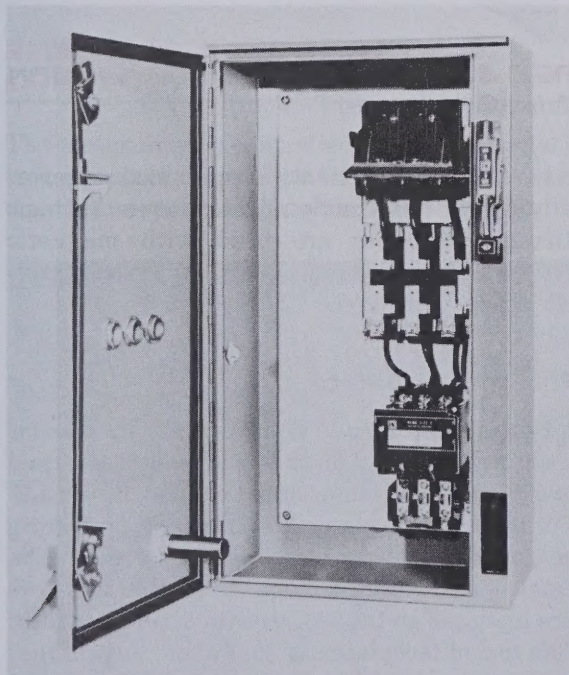


FIG. 1-4 Combination fused disconnect switch and motor starter (Courtesy Square D Co.)

Running

The maintaining of desired operational speeds and characteristics is a prime purpose and function of controllers. They protect motors, operators, machines, and materials while running. There are many different types of safety circuits and devices to protect people, equipment and industrial production and processes against possible injury that may occur while the machines are running.

Speed Control

Some controllers can maintain very precise speeds for industrial processes. Other controllers can change the speeds of motors either in steps or gradually through a continuous range of speeds.

Safety of Operator

Many mechanical safeguards have been replaced or aided by electrical means of protection. Electrical control pilot devices in controllers provide a direct means of protecting machine operators from unsafe conditions.

Protection from Damage

Part of the operation of an automatic machine is to protect the machine itself and the manufactured or processed materials it handles. For example, a certain machine control function may be the prevention of conveyor pileups. A machine control can reverse, stop, slow, or do whatever is necessary to protect the machine or processed materials.

Maintenance of Starting Requirements

Once properly installed and adjusted, motor starters will provide reliable operation of starting time, voltages, current, and torques for the benefit of the driven machine and the power system. The National Electrical Code,

supplemented by local codes, governs the selection of the proper sizes of conductors, starting fuses, circuit breakers, and disconnect switches for specific system requirements.

MANUAL CONTROL

A manual control is one whose operation is accomplished by mechanical means. The effort required to actuate the mechanism is almost always provided by a human operator. The motor may be controlled manually using any one of the following devices.

Toggle Switch

A toggle switch is a manually operated electric switch. Many small motors are started with toggle switches. This means the motor may be started directly without the use of magnetic switches or auxiliary equipment. Motors started with toggle switches are protected by the branch circuit fuse or circuit breaker. These motors generally drive fans, blowers, or other light loads.

Safety Switch

In some cases it is permissible to start a motor directly across the full line voltage if an externally-operated safety switch is used, figure 1-5. The motor receives starting and running protection from dual-element, time-delay fuses. The use of a safety switch requires manual operation. A safety switch, therefore, has the same limitations common to most manual starters.

Drum Controller

Drum controllers are rotary, manual switching devices which are often used to reverse motors and to control the speed of ac and dc motors. They are used particularly where frequent start, stop, or reverse operation is required. These controllers may be used without

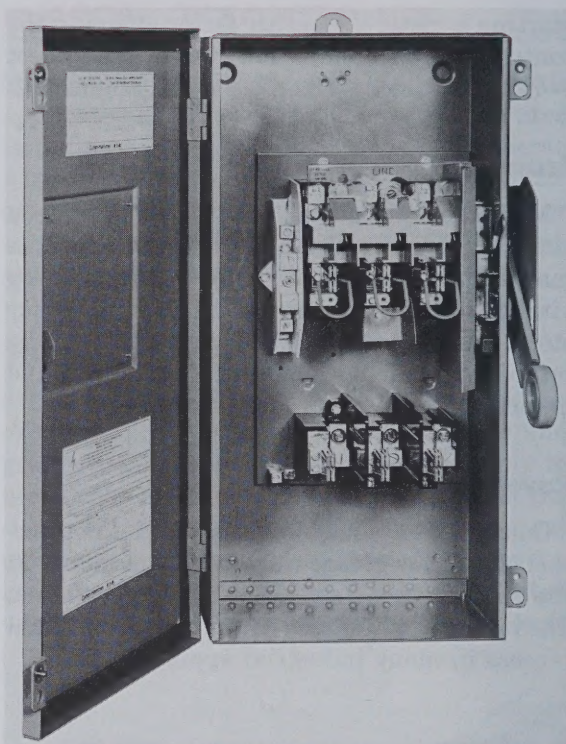


FIG. 1-5 Safety disconnect switch (Courtesy EATON Corp., Cutler-Hammer Products)

other control components in small motors, generally those with fractional horsepower ratings. Drum controllers are used with magnetic starters in large motors. A drum controller is shown in figure 1-6.

Faceplate Control

Faceplate controllers have been in use for many years to start dc motors. They are also used for ac induction motor speed control, figure 1-7. The faceplate control has multiple switching contacts mounted near a selector arm on the front of an insulated plate. Additional resistors are mounted on the rear to form a complete unit. The use of faceplate starters offers advantages and features not obtained with other manual controllers. They are also cheaper to purchase than automatic controls.

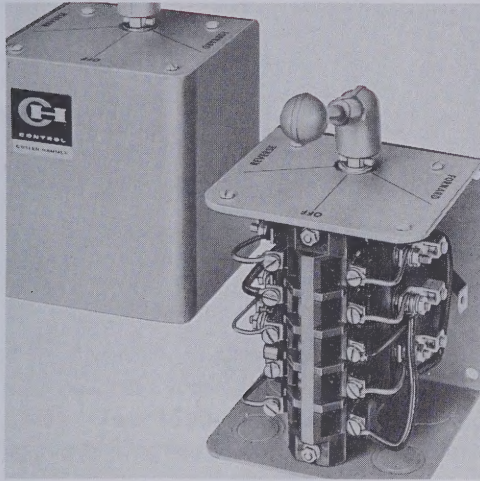


FIG. 1-6 Drum controller with cover (left) and with cover removed (right) (Courtesy Cutler-Hammer Products)

REMOTE AND AUTOMATIC CONTROL

The motor may be controlled by remote control using push buttons, figure 1-8 A and B. When push button remote control is used or when auto-

FIG. 1-7 One type of faceplate controller (Courtesy EATON Corp., Cutler-Hammer Products)

matic devices do not have the electrical capacity to carry the motor starting and running currents, magnetic switches must be included. Magnetic switch control is one whose operation is accomplished by electromagnetic means. The effort required to actuate the electromagnet is supplied by electrical energy rather than by the human operator. If the motor is to be automatically controlled, the following two-wire pilot devices may be used.

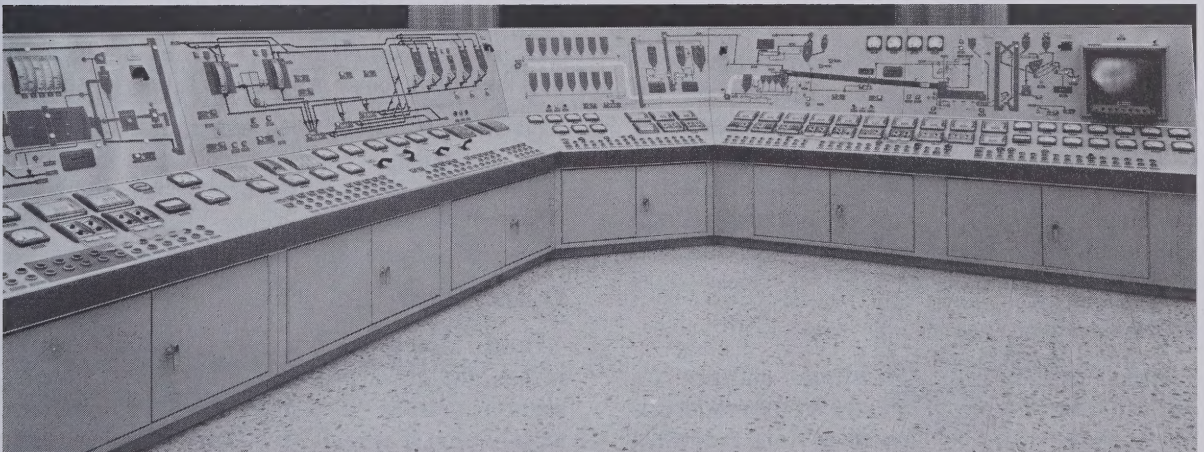
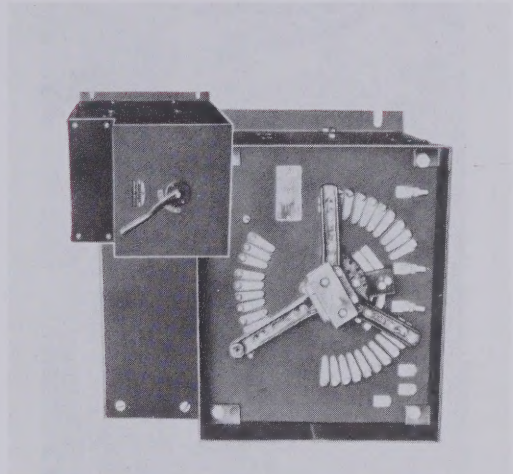


FIG. 1-8(A) Typical cement mill computer console carefully controlling and monitoring motors located remotely (Courtesy Electric Machinery Mfg. Co.)

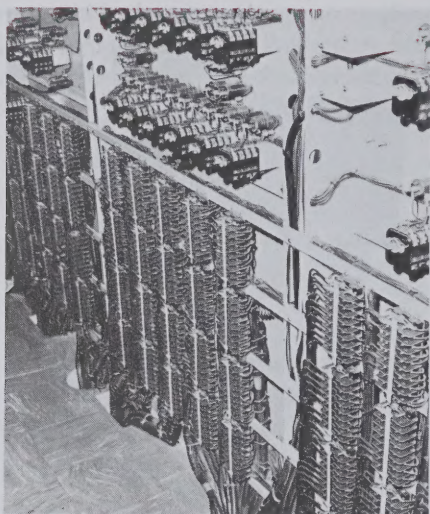


FIG. 1-8(B) Some typical terminal wiring behind the control panels shown in part A (Courtesy Los Angeles Department of Water and Power)

Float Switch

The raising or lowering of a float which is mechanically attached to electrical contacts may start motor-driven pumps to empty or fill tanks. Float switches are also used to open or close piping solenoid valves to control fluids, figure 1-9.

Pressure Switch

Pressure switches are used to control the pressure of liquids and gases (including air) within a desired range, figure 1-10. Air compressors, for example, are started directly or indirectly on a call for more air by a pressure switch. Electrical wiring symbols are shown as normally closed and normally open in figure 1-10.

Time Clock

Time clocks can be used when a definite "on and off" period is required and adjustments are not necessary for long periods of time. A typical requirement is a motor that must start every morning at the same time and shut off every

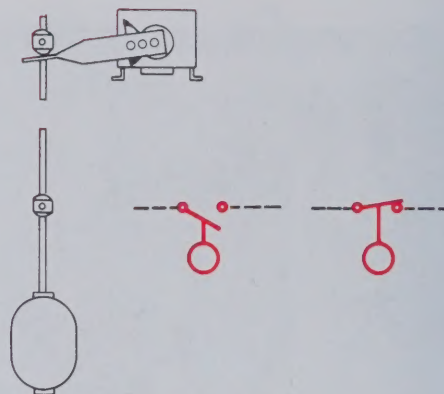


FIG. 1-9 Rod-operated float switch with electrical wiring symbols

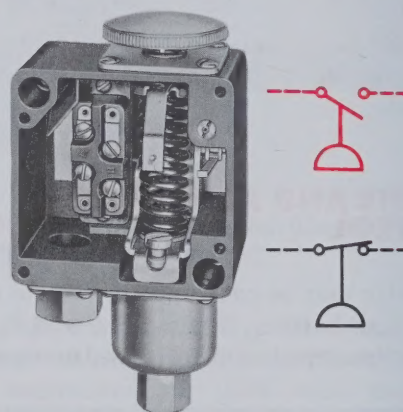


FIG. 1-10 Pressure switches may be necessary to start the motors shown in figure 1-11 (Courtesy Square D Co.)

night at the same time, or switches the flood-lights on and off.

Thermostat

In addition to pilot devices sensitive to liquid levels, gas pressures, and time of day, thermostats sensitive to temperature changes are widely used, figure 1-12. Thermostats indirectly control large motors in air conditioning systems and in many industrial applications to maintain

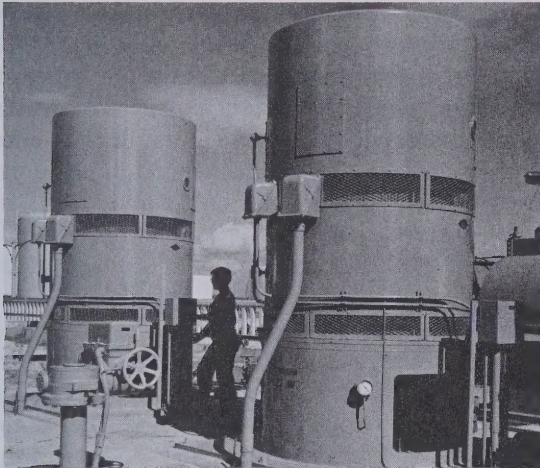


FIG. 1-11 Two 1500-hp vertical induction motors driving pumps (Courtesy Electrical Machinery Mfg. Co.)

the desired temperature range of air, gases, liquids, or solids. There are many types of thermostats and temperature-actuated switches.

Limit Switch

Limit switches, figure 1-13, are designed to pass an electrical signal only when a predetermined limit is reached. The limit may be a specific position for a machine part or a piece of work, or a certain rotating speed. These devices take the place of a human operator and are often used under conditions where it would be impossible or impractical for the operator to be present or to efficiently direct the machine.

Limit switches are used most frequently as overtravel stops for machines, equipment, and products in process. These devices are used in the control circuits of magnetic starters to govern the starting, stopping, or reversal of electric motors.

Electrical or Mechanical Interlock and Sequence Control

Many of the electrical control devices described in this unit can be connected in an interlocking system so that the final operation of one or more

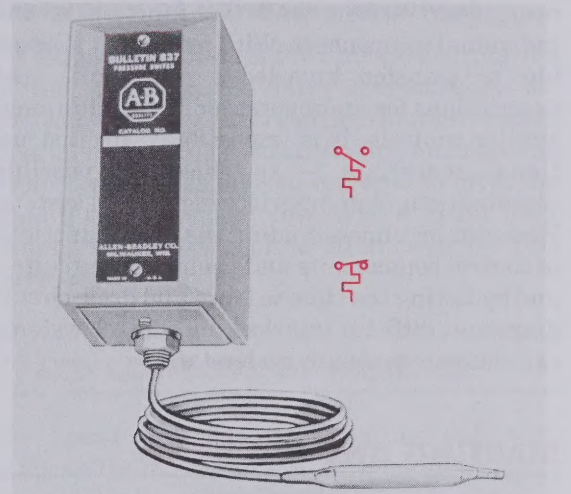


FIG. 1-12 Industrial temperature switch with extension bulb and electrical wiring symbols (Courtesy Allen-Bradley Co.)

motors depends upon the electrical position of each individual control device. For example, a float switch may call for more liquid but will not be satisfied until the prior approval of a pressure switch or time clock is obtained. To design, install, and maintain electrical controls in any electrical or mechanical interlocking system, the electrical technician must understand the total

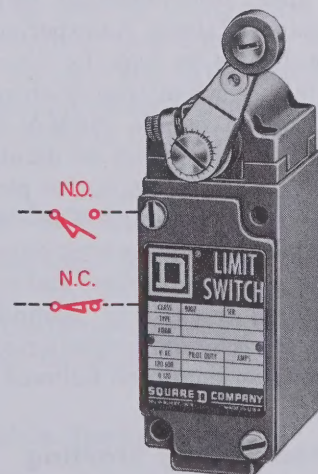


FIG. 1-13 Limit switch shown with electrical wiring symbols (Courtesy Square D Co.)

operational system and the function of the individual components. With practice, it is possible to transfer knowledge of circuits and descriptions for an understanding of additional similar controls. It is impossible — in instructional materials — to show all possible combinations of an interlocking control system. However, by understanding the basic functions of control components and their basic circuitry, and by taking the time to trace and draw circuit diagrams, difficult interlocking control systems can become easier to understand.

STARTING AND STOPPING

In starting and stopping a motor and its associated machinery, there are a number of conditions which may affect the motor. A few of them are discussed here.

Frequency of Starting and Stopping

The starting duty cycle of a controller is an important factor in determining how satisfactorily the controller will perform in a particular application. Magnetic switches, such as motor starters, relays, and contactors, actually beat themselves apart from repeated opening and closing thousands of times. An experienced electrician soon learns to look for this type of component failure when trouble-shooting any inoperative control panels. NEMA standards require that the starter size be derated if the frequency of start-stop, jogging, or plugging is more than 5 times per minute. Therefore, when the frequency of starting the controller is great, the use of heavy duty controllers and accessories should be considered. For standard duty controllers, more frequent inspection and maintenance schedules should be followed.

Light or Heavy Duty Starting

Some motors may be started with no loads and others must be started with heavy loads. When

motors are started, large feeder line disturbances may be created which can affect the electrical distribution system of the entire industrial plant. The disturbances may even affect the power company's system. As a result, the power companies and electrical inspection agencies place certain limitations on "across-the-line" motor starting.

Fast or Slow Start (Hard or Soft)

To obtain the maximum twisting effort (torque) of the rotor of an ac motor, the best starting condition is to apply full voltage to the motor terminals. The driven machinery, however, may be damaged by the sudden surge of motion. To prevent this type of damage to machines, equipment, and processed materials, some controllers are designed to start slowly and then increase the motor speed gradually in definite steps. This type is often used by power companies and inspection agencies to avoid electrical line surges.

Smooth Starting

Although reduced electrical and mechanical surges can be obtained with a step-by-step motor starting method, very smooth and gradual starting will require different controlling methods. These are discussed in detail later in the text.

Manual or Automatic Starting and Stopping

While the manual starting and stopping of machines by an operator is still a common practice, many machines and industrial processes are started and restarted automatically. These automatic devices result in tremendous savings of time and materials. Automatic stopping devices are used in motor control systems for the same reasons. Automatic stopping devices greatly reduce the safety hazards of operating some types of machinery, both for the operator and the materials being processed. An electrically oper-

ated, mechanical brake is shown in figure 1-14. Such a brake may be required to stop a machine's motion in a hurry to protect materials being processed or people in the area.

Quick Stop or Slow Stop

Many motors are allowed to coast to a standstill. However, manufacturing requirements and safety considerations often make it necessary to bring machines to as rapid a stop as possible. Automatic controls can retard and brake the speed of a motor and also apply a torque in the opposite direction of rotation to bring about a rapid stop. This is referred to as "plugging." Plugging can only be used if the driven machine and its load will not be damaged by the reversal of the motor torque. The control of deceleration is one of the important functions of a motor controller.

Accurate Stops

An elevator must stop at precisely the right location so that it is aligned with the floor level. Such accurate stops are possible with the use of automatic devices interlocked with control systems.

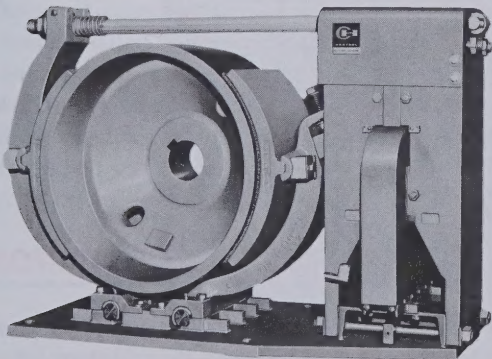


FIG. 1-14 Typical 30-inch brake (Courtesy EATON Corp., Cutler-Hammer Products)

Frequency of Reversals Required

Frequent reversals of the direction of rotation of the motor impose large demands on the controller and the electrical distribution system. Special motors and special starting and running protective devices may be required to meet the conditions of frequent reversals. A heavy duty drum switch-controller is often used for this purpose.

SPEED CONTROL OF MOTORS

The speed control is concerned not only with starting the motor but also with maintaining or controlling the motor speed while it is running. There are a number of conditions to be considered for speed control.

Constant Speed

Constant speed motors are used on water pumps, figures 1-11 and 1-15. Maintenance of constant speed is essential for motor generator sets under all load conditions. Constant speed motors with ratings as low as 80 rpm and horsepower ratings up to 5000 hp are used in direct drive units. The simplest method of changing speeds is by gearing. Using gears, almost any "pre-determined" speed may be developed by coupling the input gear to the shaft of a squirrel-cage induction motor. A speed-reducing gear motor is shown in figure 1-16.

Varying Speed

A varying speed is usually preferred for cranes and hoists, figure 1-17. In this type of application, the motor speed slows as the load increases and speeds up as the load decreases.

Adjustable Speed

With adjustable speed controls, an operator can gradually adjust the speed of a motor over a wide range while the motor is running. The

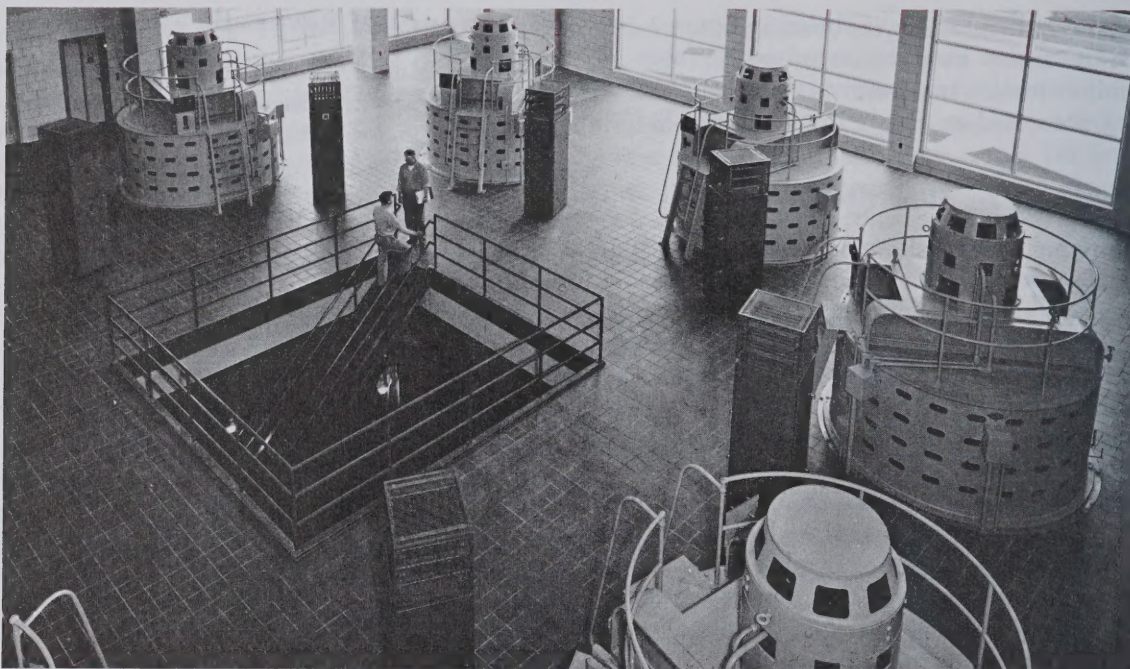


FIG. 1-15 Multiple synchronous motors of 3000-hp and 225-rpm driving water pumps (Courtesy Electric Machinery Mfg. Co.)

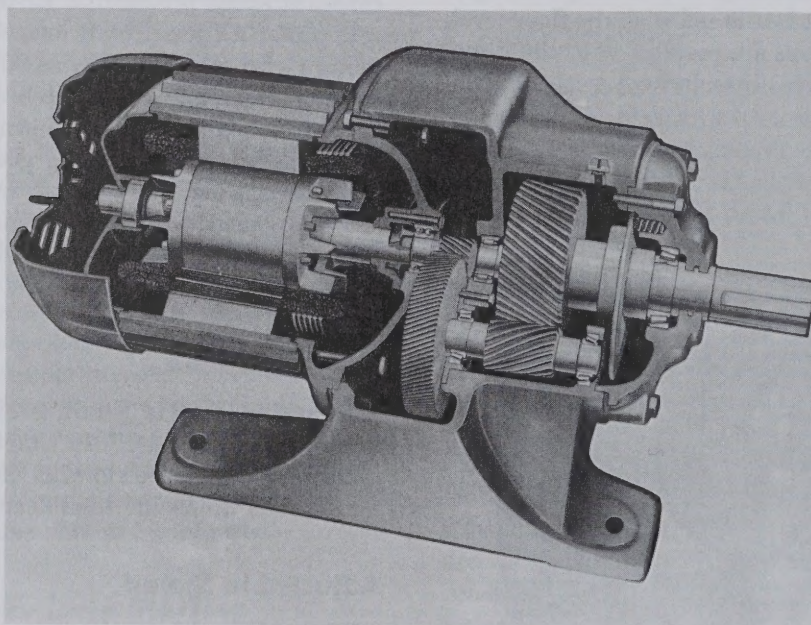


FIG. 1-16 Cutaway view of speed-reducing gear motor (double reduction) (Courtesy of U.S. Electrical Motors)

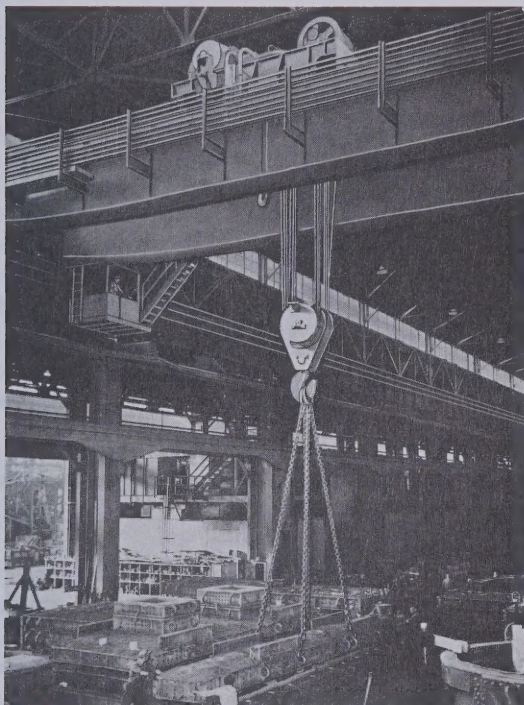


FIG. 1-17 Large traveling overhead crane (Courtesy Square D Co.)

speed may be preset, but once it is adjusted it remains essentially constant at any load within the rating of the motor.

Multispeed

For multispeed motors, such as the type used on turret lathes in a machine shop, the speed can be set at two or more definite rates. Once the motor is set at a definite speed, the speed will remain practically constant regardless of load changes.

PROTECTIVE FEATURES

The particular application of each motor and control installation must be considered to determine what protective features are required to be installed and maintained.

Overload Protection

Running protection and overload protection refer to the same thing. This protection may be an integral part of the motor or be separate. A controller with electrical overload protection will protect a motor from burning up while allowing the motor to achieve its maximum available power under a range of overload and temperature conditions. An electrical overload on the motor may be caused by mechanical overload on driven machinery, a low line voltage, an open electrical line in a polyphase system resulting in single-phase operation, motor problems such as too badly worn bearings, loose terminal connections, or poor ventilation within the motor.

Open Field Protection

Dc shunt and compound-wound motors can be protected against the loss of field excitation by field loss relays. Other protective arrangements are used with starting equipment for dc and ac synchronous motors. Some sizes of dc motors may race dangerously with the loss of field excitation while other motors may not race due to friction and the fact that they are small.

Open-Phase Protection

Phase failure in a three-phase circuit may be caused by a blown fuse, an open connection, a broken line or other reasons. If phase failure occurs when the motor is at a standstill during attempts to start, the stator currents will rise to a very high value and will remain there, but the motor will remain stationary (not turn). Since the windings are not properly ventilated while the motor is stationary, the heating produced by the high currents may damage them. Dangerous conditions also are possible while the motor is running. When the motor is running and an open-phase condition occurs, the motor may continue to run. The torque will decrease, possibly to the point of motor "stall"; this condition is called *breakdown torque*.

Reversed Phase Protection

If two phases of the supply of a three-phase induction motor are interchanged (phase reversal), the motor will reverse its direction of rotation. In elevator operation and industrial applications, this reversal can result in serious damage. Phase failure and phase reversal relays are safety devices used to protect motors, machines, and personnel from the hazards of open-phase or reversed-phase conditions.

Overtravel Protection

Control devices are used in magnetic starter circuits to govern the starting, stopping, and reversal of electric motors. These devices can be used to control regular machine operation or they can be used as safety emergency switches to prevent the improper functioning of machinery.

Overspeed Protection

Excessive motor speeds can damage a driven machine, materials in the industrial process, or the motor. Overspeed safety protection is provided in control equipment for paper and printing plants, steel mills, processing plants, and the textile industry.

Reversed Current Protection

Accidental reversal of currents in direct-current controllers can have serious effects. Direct-current controllers used with three-phase alternating-current systems which experience phase failures and phase reversals are also subject to damage. Reverse current protection is an important provision for battery charging and electroplating equipment.

Mechanical Protection

An enclosure may increase the life span and contribute to the trouble-free operation of a

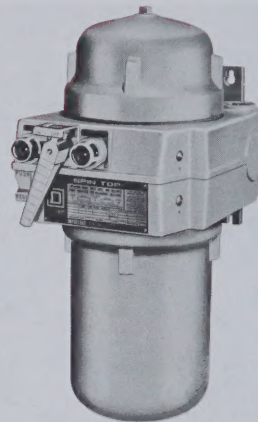


FIG. 1-18 Spin-on, explosion-proof enclosure for a combination disconnect switch and magnetic motor starter (Courtesy Square D Co.)

motor and controller. Enclosures with particular ratings such as general purpose, watertight, dustproof, explosionproof, and corrosion resistant are used for specific applications, figure 1-18. All enclosures must meet the requirements of national and local electrical codes and building codes.

Short Circuit Protection

For large motors with greater than fractional horsepower ratings, short circuit and ground fault protection generally is installed in the same enclosure as the motor-disconnecting means. Overcurrent devices (such as fuses and circuit breakers) are used to protect the motor branch circuit conductors, the motor control apparatus, and the motor itself against sustained overcurrent due to short circuits and grounds, and prolonged and excessive starting currents.

CLASSIFICATION OF AUTOMATIC MOTOR STARTING CONTROL SYSTEMS

The numerous types of automatic starting and control systems are grouped into the following

classifications: current limiting acceleration and time delay acceleration.

Current Limiting Acceleration

This is also called Compensating Time. It refers to the amount of current or voltage drop required to open and close magnetic switches when used in a motor accelerating controller. The rise and fall of the current or voltage determines a timing period which is used mainly for dc motor control. Examples of types of current limiting acceleration are:

- Counter emf or voltage drop acceleration
- Lockout contactor or series relay acceleration

Time Delay Acceleration

For this classification, *definite time* relays are used to obtain a preset timing period. Once the period is preset, it does not vary regardless of current or voltage changes occurring during motor acceleration. The following timers and timing systems are used for motor acceleration; some are also used in interlocking circuits for automatic control systems.

- Individual dashpot relays
- Multicircuit dashpot relays
- Pneumatic timing
- Inductive time limit acceleration
- Motor-driven timers
- Capacitor timing
- Electronic timers

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What is a controller and what is its function? (Use the glossary in the Appendix and the information from this unit to answer this question.)
2. What is meant by remote control?
3. To what does current limiting, or compensating time, acceleration refer?
4. List some devices that are used to control a motor automatically. Briefly describe the purpose of each device.

Select the *best* answer for each of the following.

5. The general purpose of motor control is
 - a. to start the motor
 - b. to stop the motor
 - c. to reverse the motor
 - d. all of the above
6. A motor may be controlled manually by using a
 - a. float switch
 - b. pressure switch
 - c. toggle switch
 - d. time clock

7. A motor may be controlled remotely or automatically by using a
 - a. drum controller
 - ☒ b. thermostat
 - c. safety switch
 - d. faceplate control
8. Conditions which may affect starting and stopping of motor driven machinery are
 - a. fast or slow starts
 - b. light or heavy duty starting
 - c. frequency of starting and stopping
 - ☒ d. all of the above
9. Which factor is *not* to be considered for motor speed control when the motor is running?
 - a. Constant speed
 - b. Varying speed
 - c. Multispeed
 - ☒ d. Starting protection
10. Which is not considered a motor controller protective feature?
 - a. Overload
 - b. Short-circuit
 - ☒ c. Adjustable speed
 - d. Mechanical
11. Which function is not a fundamental job of a motor controller?
 - a. Start and stop the motor
 - b. Protect the motor, machine, and operator
 - c. Reverse, inch, jog, speed control
 - ☒ d. Motor disconnect switch and starting protection
12. What factors are to be considered when selecting and installing a controller?
 - a. Electrical service
 - b. Motor
 - c. Electrical codes and standards
 - ☒ d. All of the above

UNIT 2 *Fractional and Integral Horsepower Manual Motor Starters*

Objectives After studying this unit, the student will be able to:

- Match simple schematic diagrams with the appropriate manual motor starters
- Connect manual fractional horsepower motor starters for automatic and manual operation
- Connect integral horsepower manual starters
- Explain the principles of operation of manual motor starters
- List common applications of manual starters
- Read and draw simple schematic diagrams
- Briefly explain how motors are protected electrically

FRACTIONAL HORSEPOWER MANUAL MOTOR STARTERS

One of the simplest types of motor starters is an on-off, snap action switch operated by hand on a toggle lever mounted on the front of the starter, figure 2-1. The motor is connected directly across the matching line voltage when the handle is turned to the START position. This situation usually is not objectionable with motors rated at one horsepower (hp) or less. Since a motor may draw up to a 600-percent current surge on starting, larger motors should not be connected directly across the line on startup. Such a connection would result in large line surges that may disrupt power services or cause voltage fluctuations which impede the normal operation of other equipment. Proper motor starters for larger motors are discussed later.

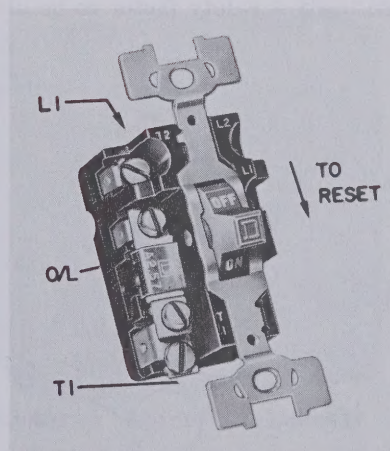


FIG. 2-1 Open-type starter with overload heater
(Courtesy Square D Co.)

Fractional horsepower (FHP) manual motor starters are used whenever it is desired to provide overload protection for a motor as well as “off” and “on” control of small alternating-current single-phase or direct-current motors. Electrical codes require that fractional horsepower motors be provided with overload protection whenever they are started automatically or by remote control. Basically, a manual starter is an *on-off* switch with motor overload protection.

Since manual starters are hand-operated mechanical devices (requiring no electrical coil), the contacts remain closed and the lever stays in the ON position in the event of a power failure. As a result, the motor automatically restarts when the power returns. Therefore, low-voltage protection (see glossary in the Appendix) is not possible with manually operated starters. This automatic restart action is an advantage when the starter is used with motors that run continuously, such as those used on unattended pumps, blowers, fans, and refrigeration processes. This saves the maintenance electrician from running around the plant to restart all these motors after the power returns. On the other hand, the automatic restart feature is a disadvantage on lathes and machines that may be a danger to products, machinery, or people. It is definitely a safety factor to be observed.

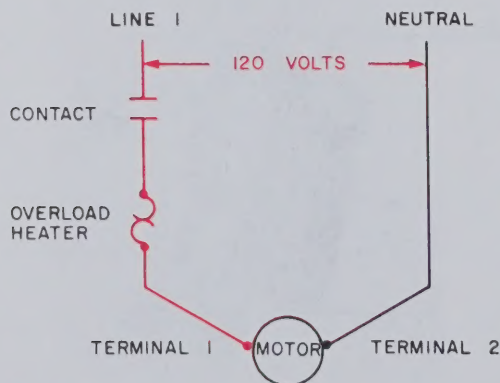


FIG. 2-2 Diagram of single-pole manual starter shown in Fig. 2-1

The compact construction of the manual starter means that it requires little mounting space and can be installed on the driven machinery and in various other places where the available space is limited. The unenclosed, or open starter, can be mounted in a standard switch or conduit box installed in a wall and can be covered with a standard flush, single-gang switchplate. The ON and OFF positions are clearly marked on the operating lever, which is very similar to a standard lighting toggle switch lever, figure 2-1.

Application

Fractional horsepower manual starters have thermal overload protection, figures 2-1 and 2-2. When an overload occurs, the starter handle automatically moves to the center position to signify that the contacts have opened and the motor is no longer operating. The starter contacts cannot be reclosed until the overload relay is reset manually. The relay is reset by moving the handle to the full OFF position after allowing about two minutes for the heater to

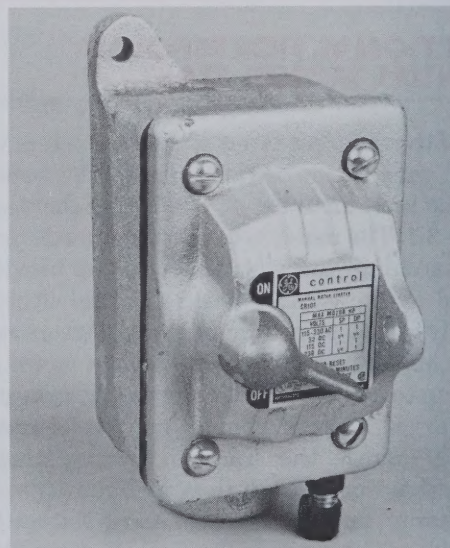


FIG. 2-3 Water-tight and dust-tight manual starter enclosure (Courtesy General Electric Co.)

cool. Should the circuit trip open again, the fault should be located and corrected.

Fractional horsepower manual starters are provided in several different types of enclosures as well as the open type to be installed in a switch-box, flush in the wall, or on the surface. Enclosures are obtained to shield the live starter circuit components from accidental contact, for mounting in machine cavities, to protect the starter from dust and moisture, figure 2-3, or to prevent the possibility of an explosion when the starter is used in hazardous locations. These different types of enclosures will be discussed in more detail in Unit 3.

AUTOMATIC AND REMOTE OPERATION

Common applications of manual starters provide control of small machine tools, fans, pumps, oil burners, blowers, and unit heaters. Almost any small motor should be controlled with a starter of this type. However, the contact capacity of the starter must be sufficient to make and break the full motor current. Automatic control devices such as pressure switches, float switches, or thermostats rated to carry motor current may be used with fractional horsepower manual starters.

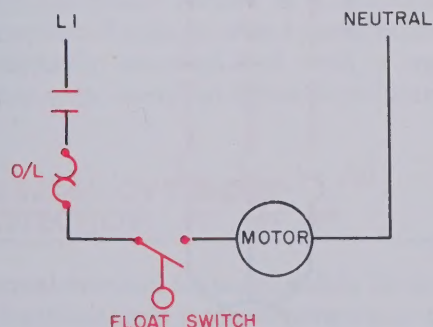


FIG. 2-4 Automatic control with FHP-single-pole, single-phase manual starter for fractional hp motor without selector switch

The schematic diagram shown in figure 2-4 illustrates a fractional horsepower motor controlled automatically by a float switch that is remotely connected in the small motor circuit as long as the manual starter contact is closed. When the float is up, the pump motor starts.

In figures 2-5 and 2-6, the selector switch must be turned to the automatic position if the float switch is to take over an automatic operation, such as sump pumping. A liquid filled sump raises the float, closes the normally open electrical contact, and starts the motor. When the

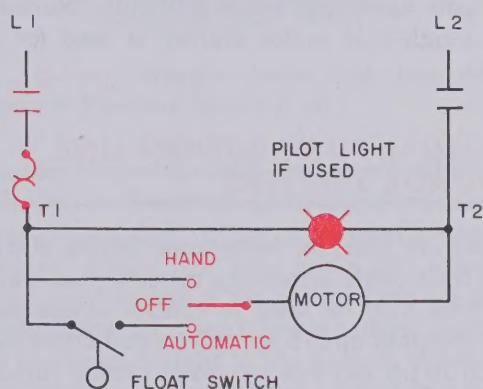


FIG. 2-5 Manual FHP-double-pole, single-phase starter with automatic control for fractional hp motor using selector switch (See Fig. 2-6)

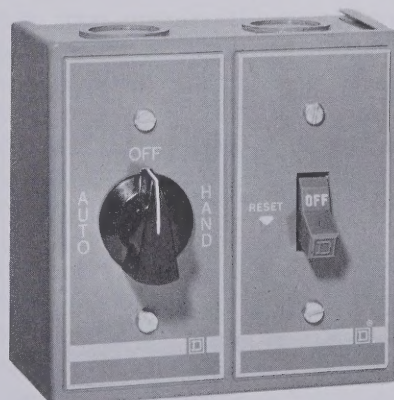


FIG. 2-6 Fractional hp manual starter with selector switch, mounted in general-purpose enclosure (Courtesy Square D Co.)

motor pumps the sump or tank empty, the float lowers and breaks electrical contact with the motor thus stopping the motor. This cycle of events will repeat when the sump fills again, automatically, without a human operator.

Note that a double-pole starter is used in figure 2-5. This type of starter is required when both lines to the motor must be broken such as for 230 volts, single phase. The double-pole starter is also recommended for heavy-duty applications because of its higher interrupting capacity and longer contact life, when using a two-pole motor starter on 115 volts. Normally, the single-pole motor starter is used for 115 volts.

MANUAL PUSH-BUTTON LINE VOLTAGE STARTERS

These are integral horsepower motor starters (not fractional). Generally, manual push-button starters may be used to control single-phase motors rated up to 5 hp, polyphase motors rated up to 10 hp and direct-current motors rated up to 2 hp. They are available in two-pole for single-phase and three-pole for polyphase motors. A typical manual three-phase push-button starter and diagram are shown in figures 2-7 and 2-8.

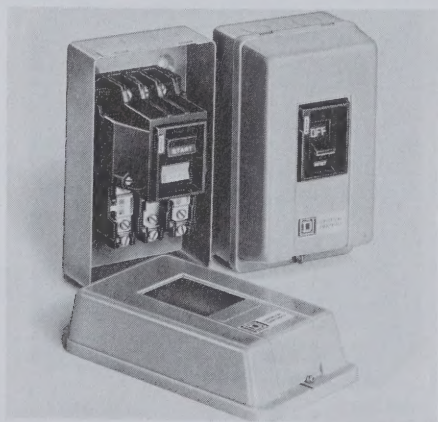


FIG. 2-7 Three-phase line voltage manual starter mounted in a general purpose enclosure (Courtesy Square D Co.)

When an overload relay trips, the starter mechanism unlatches, opening the contacts to stop the motor. The contacts cannot be reclosed until the starter mechanism has been reset by pressing the STOP button, after allowing time for the thermal unit to cool.

These starters are designed for infrequent starting of small ac motors. This manual starter provides overload protection also, but cannot be used where low or undervoltage protection is required or for remote or automatic operation.

Manual Starter with Low Voltage Protection

Integral horsepower manual starters with Low Voltage Protection (LVP) prevent automatic start-up of motors after a power loss. This is accomplished with a continuous-duty electrical solenoid which is energized whenever the line-side voltage is present and the start button is pressed, figure 2-9. If the line voltage is lost or disconnected, the solenoid de-energizes, opening the starter contacts. The contacts will not automatically re-close when the line voltage is restored. To close the contacts to restart the motor again, the device must be manually reset. This manual starter will not function unless the line terminals are energized. This starter should not be confused with magnetic starters described

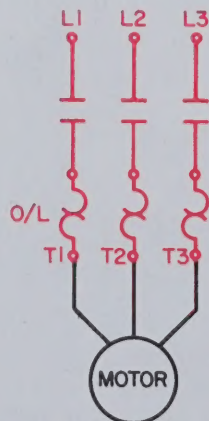


FIG. 2-8 Wiring diagram for the three-pole line voltage push-button manual starter seen in Fig. 2-7

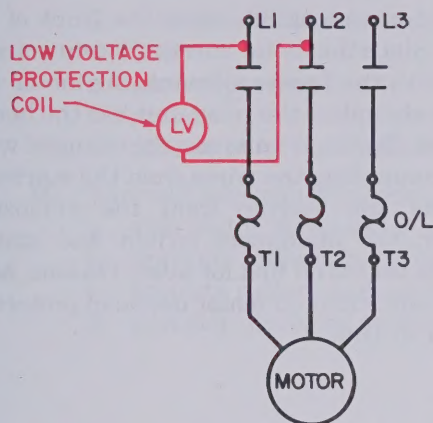


FIG. 2-9(A) Wiring diagram for integral hp manual starter with low-voltage protection.

in the next unit. This is *not* a magnetic starter, but a lower cost starter.

Applications

Typical applications include conveyor lines, grinders, metal working machinery, mechanical power presses, mixers, woodworking machinery and wherever job specifications and standards require low-voltage protection, or wherever machine operator safety could be in jeopardy.

Therefore, this manually operated, push-button starter with low-voltage protection is a method of protecting an operator from injury using automatic restart of a machine upon resumption of voltage, after a power failure. This is normally accomplished with a magnetic starter with electrical (three-wire) control.

THERMAL OVERLOAD PROTECTION

Thermal overload units are widely used on both the fractional and integral horsepower manual starters for protection of motors from sustained electrical overcurrents that could result from overloading of the driven machine or from excessively low line voltage.

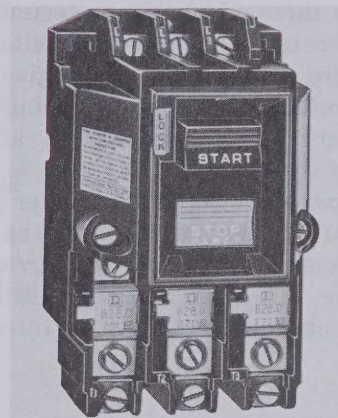


FIG. 2-9(B) Manual starter with low-voltage protection (Courtesy Square D Co.)

Heater elements which are closely calibrated to the full load current of the motor are used on the solder-pot and the thermobimetallic types of overload relays. On the solder-pot overload relays, the heating of the element causes alloy elements to melt when there is a motor overload due to excess current in the circuit. When the alloy melts, a spring-loaded ratchet is rotated and trips open a contact which then opens the supply circuit to the motor; this stops the motor. On the bimetallic overload relays, the heating from the thermal element causes the bimetallic switch to open, opening the supply circuit and thereby stopping the motor.

Normal motor starting currents and momentary overloads will not cause thermal relays to trip because of their inverse-time characteristics (see glossary in the Appendix). However, continuous overcurrent through the heater unit raises the temperature of the alloy elements. When the melting point is reached, the ratchet is released and the switch mechanism is tripped to open the line or lines to the motor. The switch mechanism is trip-free, which means that it is impossible to hold the contacts closed against an overload.

Only one overload relay is required in either the single-pole or double-pole motor starter, since the starter is intended for use on dc or single-phase ac service. When the line current is exces-

sively high, these relays offer protection against continued operation. Relays with meltable alloy elements are nontemperable and give reliable overload protection. Repeated tripping does not cause deterioration nor does it affect the accuracy of the trip point.

Many types of overload relay heater units are available so that the proper one can be selected on the basis of the actual full-load current rating of the motor. The applicable relay heater units for a particular overload relay are interchange-

able and are accessible from the front of the starter. Since the motor current is connected in series with the heater element, the motor will not operate unless the relay unit has the heater installed. Overload units may be changed without disconnecting the wires from the starter or removing the starter from the enclosure. However, the disconnect switch and starter should be turned off first for safety reasons. Additional instruction on motor overload protection is given in Unit 3.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. If the contacts on a manual starter cannot be closed immediately after a motor overload has tripped them open, what is the probable reason?
2. If the handle of an installed motor starter is in the center position, what condition does this indicate?
3. How may a manual starter be installed or used for an automatic operation?
4. What does trip-free mean?
5. If overload heating elements are not installed in the starter, what is the result?

Select the *best* answer for each of the following.

6. A fractional horsepower manual motor starter
 - a. starts and stops motors under one horsepower
 - b. has a toggle switch type of handle and size
 - c. has no low-voltage protection
 - ☒ d. does all of these
7. An automatic operation is used with
 - a. integral hp manual starters
 - b. push-button manual starters
 - ☒ c. FHP manual starters with a pressure switch
 - d. fractional horsepower manual starters
8. Normally, low voltage (or under voltage) protection (LVP) is achieved with
 - a. a push-button manual starter
 - b. a toggle switch handle starter
 - c. both a and b
 - ☒ d. a push-button manual starter with LVP coil

9. Low voltage protection is used mainly for
 - a. fans
 - b. air compressors
 - c. pumps
 - d. protection of the operator
10. Thermal overload protection
 - a. aids motor warm-up
 - b. prevents motors from freezing
 - c. protects motors and conductors from mechanical damage
 - d. provides electrical protection of motors

UNIT 3 *Magnetic Line Voltage Starters*

Objectives After studying this unit, the student will be able to:

- Identify common magnetic motor starters and overload relays
- Describe the construction and operating principles of magnetic switches
- Describe the operating principle of a solenoid
- Troubleshoot magnetic switches
- Select starter protective enclosures for particular applications

Magnetic control means the use of electromagnetic energy to close switches. Line voltage (across the line) magnetic starters are electromechanical devices that provide a safe, convenient, and economic means of full voltage starting and stopping motors. In addition, these devices can be controlled remotely. They are used when a full-voltage starting torque (see glossary in the Appendix) may be applied safely to the driven machinery and when the current inrush resulting from across-the-line starting is not objectionable to the power system. Control for these starters is usually provided by pilot devices such as push buttons, float switches, timing relays, and more as discussed in Section 2. Automatic control is obtained from the use of some of these pilot devices.

MAGNETIC STARTERS VS MANUAL

Using manual control, the starter must be mounted so that it is easily within reach of the machine operator. With magnetic control, push-

button stations are mounted nearby, but automatic control pilot devices can be mounted almost anywhere on the machine. The push buttons and automatic pilot devices can be connected by control wiring into the coil circuit of a remotely mounted starter, possibly closer to the motor to shorten the power circuit.

Operation

In the construction of a magnetic controller, the armature is mechanically connected to a set of contacts so that, when the armature moves to its closed position, the contacts also close. There are different variations and positions, but the operating principle is the same.

The simple up-and-down motion of a solenoid-operated, three-pole magnetic switch is shown in figure 3-1. Not shown are the motor overload relays and the maintaining and auxiliary electrical contacts. Double break contacts are used on this type of starter to cut the voltage in half on each contact, thus providing high arc rupturing capacity and longer contact life.

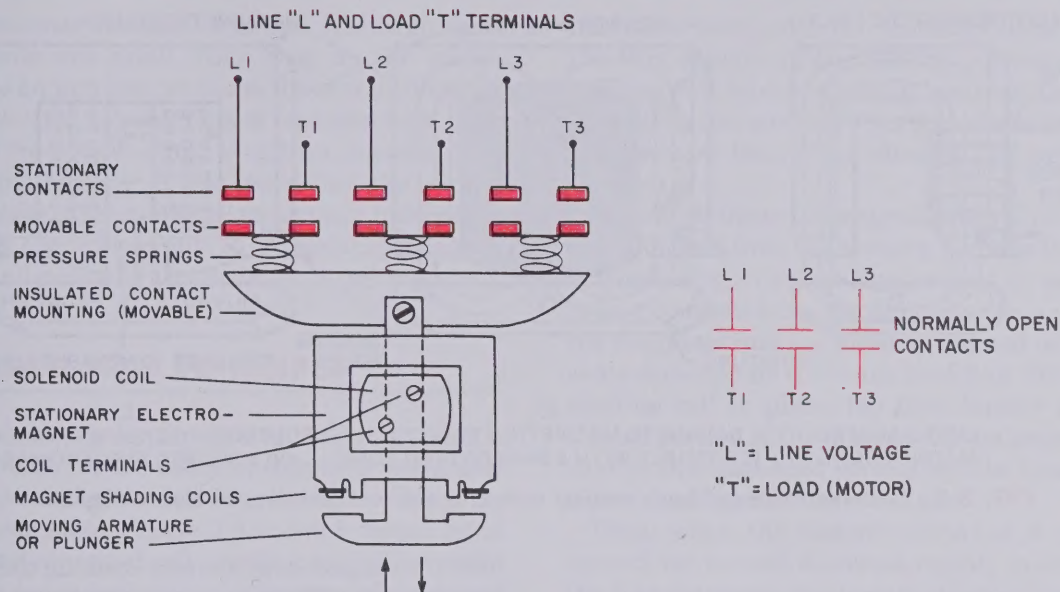


FIG. 3-1 Three-pole, solenoid-operated magnetic switch (contactor) and electrical wiring symbols

STARTER ELECTROMAGNETS

The operating principle that makes a magnetic starter different from a manual starter is the use of an electromagnet. Electrical control equipment makes extensive use of a device called a solenoid. This electromechanical device is used to operate motor starters, contactors, relays, and valves. By placing a coil of many turns of wire around a soft iron core, the magnetic flux set up by the energized coil tends to be concentrated; therefore, the magnetic field effect is strengthened. Since the iron core is the path of least resistance to the magnetic lines of force, magnetic attraction concentrates according to the shape of the magnet core.

There are several different variations in design of the basic solenoid magnetic core and coil. Figure 3-2 shows a few examples. As shown in the solenoid design of figure 3-2C, linkage to the movable contacts assembly is obtained through a hole in the movable plunger. The plunger is shown in the open de-energized position.

The center leg of each of the E-shaped magnet cores in figures 3-2B and C is made shorter than the outside legs to prevent the magnetic switch from accidentally staying closed (due to residual magnetism) when power is disconnected.

Figure 3-3 shows a manufactured magnet structure and how the starter contacts are mounted on the armature.

When a magnetic motor starter coil is energized and the armature has sealed-in, it is held tightly against the magnet assembly. A small air gap is always deliberately placed in the center leg, iron circuit. When the coil is de-energized, a small amount of magnetism remains. If it were not for this gap in the iron circuit, the residual magnetism might be enough to hold the moveable armature in the sealed-in position. This knowledge can be important to the electrician when troubleshooting a motor that will not stop.

The OFF or OPEN position is obtained by de-energizing the coil and allowing the force of gravity or spring tension to release the plunger

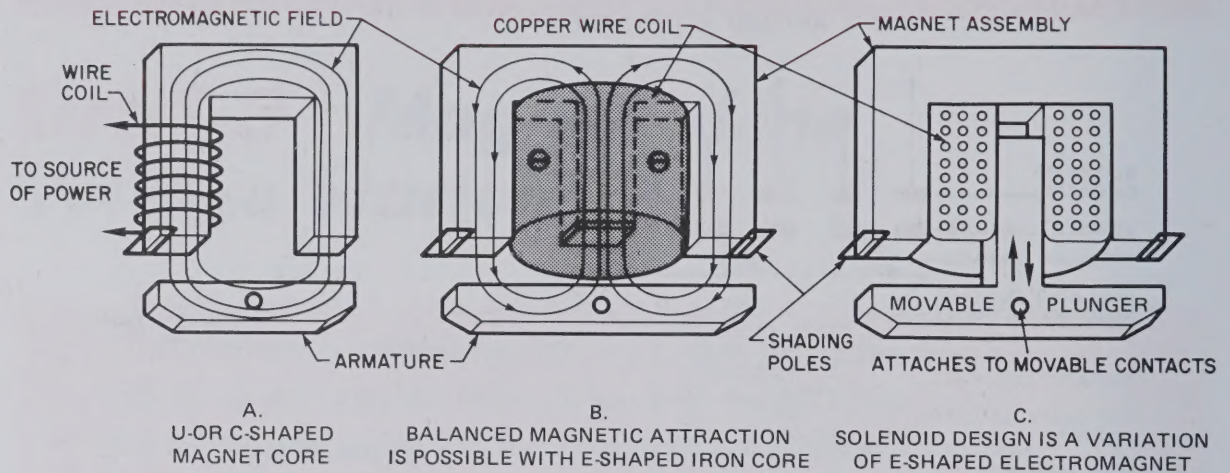


FIG. 3-2 Some variations of basic magnet core and coil configurations of electromagnets

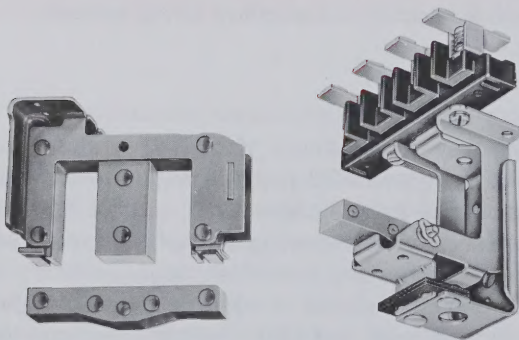
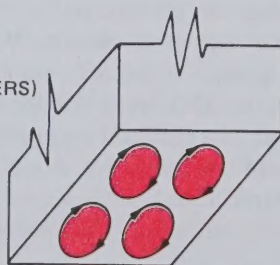


FIG. 3-3 Magnet structure (left) and movable contacts and armature guide assembly (right) of a four-pole magnetic switch (Courtesy Square D Co.)

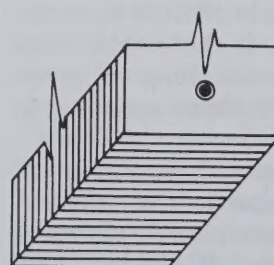
from the magnet body, thereby opening the electrical contacts. The actual contact surfaces of the plunger and core body are machine finished to insure a high degree of flatness on the contact surfaces so that operation on alternating current is quieter. Improper alignment of the contacting surfaces and foreign matter between the surfaces may cause a noisy hum on alternating-current magnets.

Another source of noise is due to loose laminations. The magnet body and plunger (armature) are made up of thin sheets of iron laminated and riveted together to reduce *eddy currents* and hysteresis, iron losses showing up as heat (see figure 3-4). Eddy currents are shorted currents induced in the metal by the

EDDY CURRENTS INDUCED IN A SOLID CORE IF USED ON AC (FOR DC CONTROLLERS)



A. SOLID CORE



B. LAMINATED CORE

AC MAGNETS ARE LAMINATED AND RIVETED TOGETHER TO REDUCE THE HEATING EFFECT OF EDDY CURRENTS.

FIG. 3-4 Types of magnet cores

transformer action of an ac coil. Although these currents are small, they heat up the metal, create an iron loss, and contribute to inefficiency. At one time, laminations in magnets were insulated from each other by a thin, nonmagnetic coating; however, it was found that the normal oxidation of the metallic laminations reduces the effects of eddy currents to a satisfactory degree, thus eliminating the need for a coating.

SHADED POLE PRINCIPLE

The shaded pole principle is used to provide a time delay in the decay of flux in dc coils, and to prevent chatter and wear in the moving parts of ac magnets. Figure 3-5 shows a copper band or short-circuited coil (shading coil) of low resistance connected around a portion of a magnet pole piece. When the flux is increasing in the pole piece from left to right, the induced current in the shading coil is in a clockwise direction.

The magnetic flux produced by the shading coil opposes the direction of the flux of the main

field. Therefore, with the shading coil in place, the flux density in the shaded portion of the magnet will be considerably less, and the flux density in the unshaded portion of the magnet will be more than if the shading coil were not in place.

Figure 3-6 shows the magnet pole with the flux direction still from left to right, but now the flux is decreasing in value. The current in the coil is in a counterclockwise direction. As a result, the magnetic flux produced by the coil is in the same direction as the main field flux. With the shading coil in place, the flux density in the shaded portion of the magnet will be larger and that in the unshaded portion will be less than if the shading coil were not used.

Thus, when the electric circuit of a coil is opened, the current decreases rapidly to zero, but the flux decreases much more slowly because of the action of the shading coil. This produces a more stable magnetic pull on the armature as the ac wave form alternates from maximum to minimum values and helps prevent chatter and ac hum.

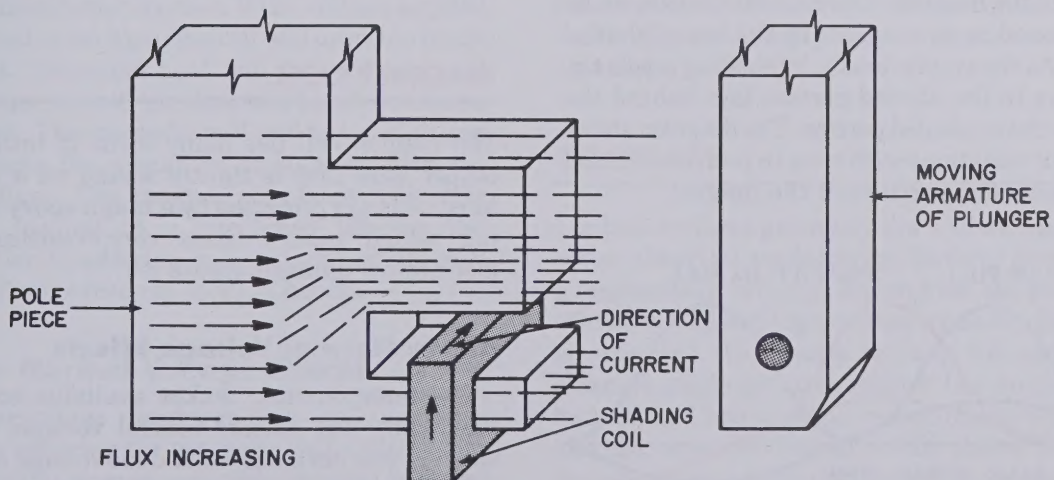


FIG. 3-5 Pole face section with shading coil; current is in the clockwise direction for increasing flux

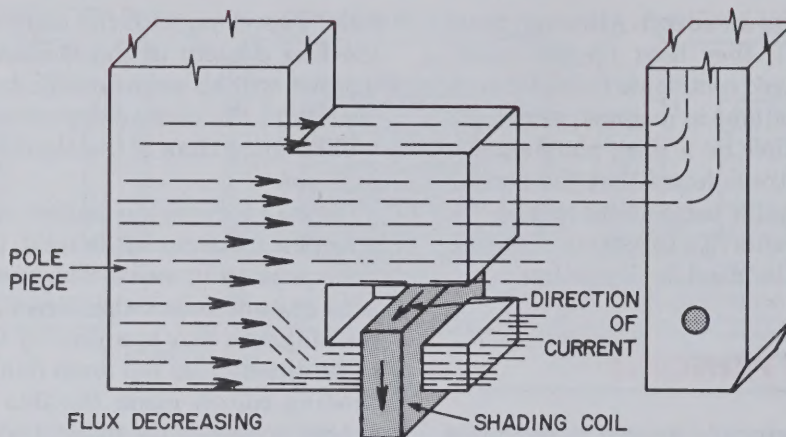
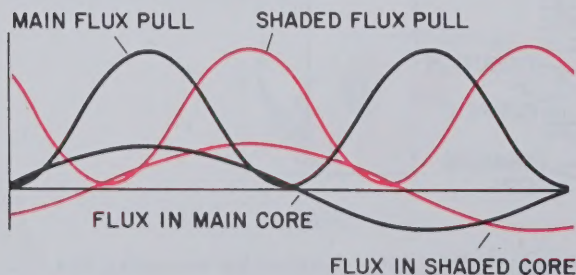


FIG. 3-6 Pole face section; current is in the counterclockwise direction for decreasing flux

Use of the Shading Pole to Prevent Wear and Noise

The attraction of an electromagnet operating on alternating current is pulsating and equals zero twice during each cycle. The pull of the magnet on its armature also drops to zero twice during each cycle. As a result, the sealing surfaces of the magnet tend to separate each time the flux is zero and then contact again as the flux builds up in the opposite direction. This continual making and breaking of contact will result in a noisy starter and wear on the moving parts of the magnet. The noise and wear can be eliminated in ac magnets by the use of shaded poles. As shown previously, by shading a pole tip, the flux in the shaded portion lags behind the flux in the unshaded portion. The diagram shows the flux variations with time in both the shaded and unshaded portions of the magnet.



The two flux waves are made as near 90 degrees apart as possible. Pull produced by each flux is also shown. If flux waves are exactly 90° apart, the pulls will be 180° apart, the resultant pull will be constant. However, with fluxes *nearly* 90° apart, the resulting pull varies only a small amount from its average value and never goes through zero. Voltage induced in the shading coil causes flux to exist in the electromagnet, even when the main coil current instantaneously passes through a zero point. As a result, contact between the sealing surfaces of the magnet is not broken and chattering and wear are prevented.

MAGNET COIL

The magnet coil has many turns of insulated copper wire that is tightly wound on a spool. Most coils are protected by a tough epoxy molding which makes them very resistant to mechanical damage, figure 3-7.

Above Normal Voltage Effects

The manufacturer makes available coils of practically any desired control voltage. Some starters are designed with dual-voltage coils.

NEMA standards require that the magnetic switch operates properly at varying control

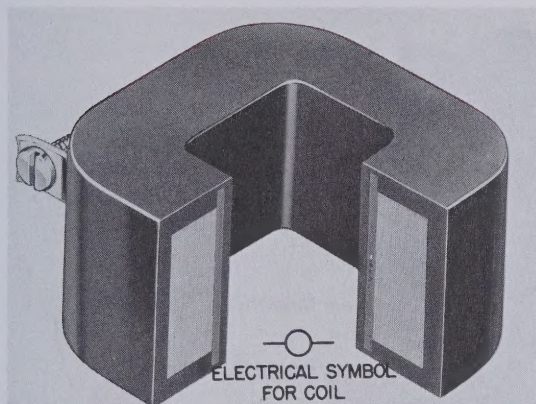


FIG. 3-7 Magnet coil cut away to show insulated copper wire wound on a spool and protected by a molding

voltages from a high of 110% to a low of 85% of the rated coil voltage. This range of required operation is then designed by the manufacturer. It insures that the coil will withstand elevated temperatures at voltages up to 10% over rated voltage and that the armature will pick-up and seal-in, even though the voltage may drop to 15% under the rating. Normally, power company service voltages are very reliable. Plant voltages may vary due to other loaded, operating machines, and other reasons affecting the electrical distribution system. If the voltage applied to the coil is too high, the coil will draw too much current. Excessive heat will be produced and may cause the coil insulation to break down and burn out. The magnetic pull will be too high and will cause the armature to slam in with too much force. The magnet pole faces will wear faster, leading to a shortened life for the controller. In addition, reduced contact life may result from excessive contact bounce.

Below Normal Voltage Effects

Undervoltage produces low coil currents thereby reducing the magnetic pull. On common starters the magnet may pick-up (start to move)

but not seal. The armature must seat against the pole faces of the magnet to operate satisfactorily. Without this condition, the coil current will not fall to the sealed value because the magnetic circuit is open, decreasing impedance (ac resistance). As the coil is not designed to continuously carry a current greater than its sealed current, it will quickly get very hot and burn out. The armature will also chatter. In addition to the noise, there is excessive wear on the magnet pole faces. If the armature does not seal, the contacts may touch but not close with enough pressure, creating another problem. Excessive heat, with arcing and possible welding of the contacts, will occur as the controller attempts to carry a motor-starting current with insufficient contact pressure.

POWER (OR MOTOR) CIRCUIT OF THE MAGNETIC STARTER

The number of poles refers to the number of power contacts, determined by the electrical supply service. For example, in a three-phase, three-wire system, a three-pole starter is required. The power circuit of a starter includes the main stationary and movable contacts and the thermal unit or heater unit of the overload relay assembly. This can be seen in figure 3-8(A) (and in figure 3-1, less the thermal overload relay assembly).

CONTACTS

Contact surfaces generally are a silver alloy for better electrical conductivity. Surfaces also have a mechanical “wiping” action from the point of contact to the sealing position when the starter is activated. This helps to keep the contacts clean. A good operating starter has no contact bounce, and has superior resistance to welding and arc erosion. Figure 3-8(B) shows the 45 degree wedge action design of the contact.

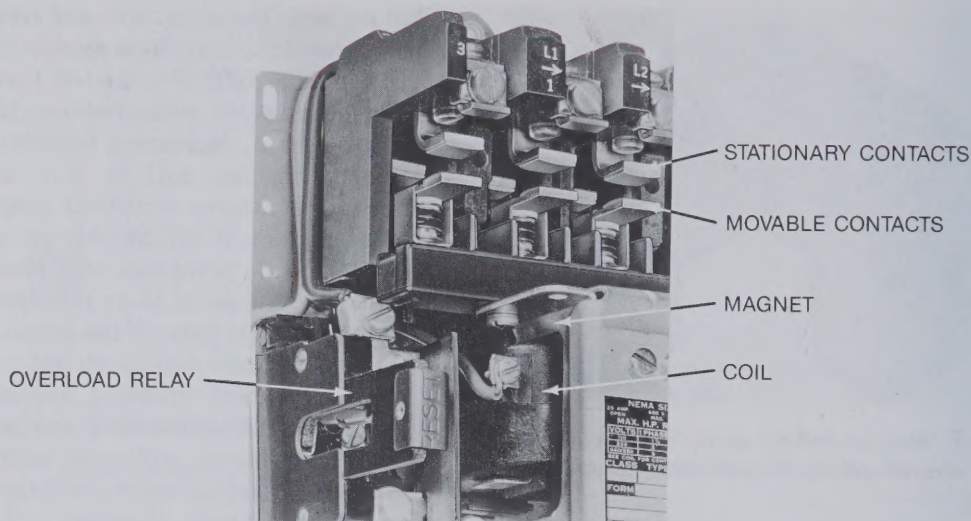


FIG. 3-8(A) Ac magnetic starter with contact arcing chamber removed. Note overload relay (lower left) and coil and magnet (lower center). (Courtesy Square D Company)

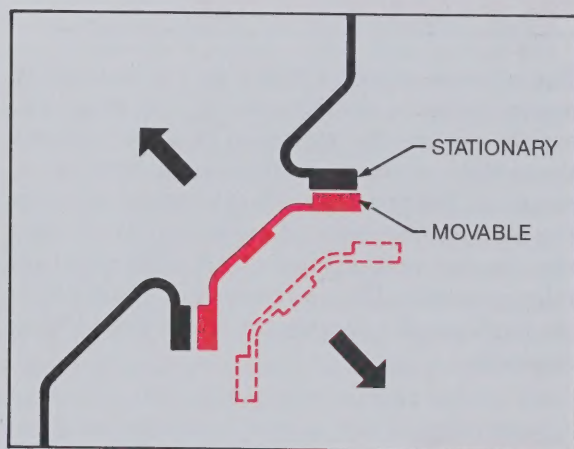


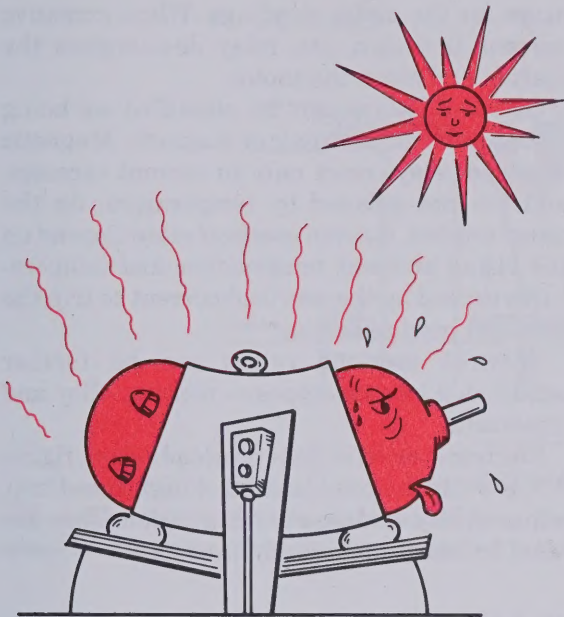
FIG. 3-8(B) 45° wedge action design contacts

MOTOR OVERHEAT

An electric motor does not know enough to quit when the load gets too much for it. It keeps going until it burns out. If a motor is subjected, over a period of time, to internal or external heat levels that are high enough to destroy the insulation on the motor windings, it will fail — burn out.

A solution to this problem *might* be to install a larger motor whose capacity is in excess of the normal horsepower required. This isn't too practical since there are other reasons for a motor to overheat besides excess loads. A motor will run cooler in winter snow country than in summer hot tropical weather. A high, surrounding air temperature (*ambient temperature*) has the same effect as higher-than-normal current flow through motor — it tends to deteriorate the insulation on the motor windings.

High ambient temperature is also created by *poor ventilation* of the motor. Motors must get rid of their heat so any obstructions to this must be avoided. High inrush currents of *excessive starting* create heat within the motor. The same is true with *starting heavy loads*. There are several other related causes that generate heat within a motor such as *voltage unbalance*, *low voltage*, single phasing. In addition, when the rotating member of the motor will not turn (a condition called *locked rotor*) heat is generated. It must be impossible to design a motor that will adjust itself for all the various changes in total heat that can occur. Some device is needed to protect a motor against expected overheating.



(EFFECTS OF HIGH AMBIENT TEMPERATURE)

Motor Overload Protection

The ideal overload protection for a motor is an element with current sensing properties very similar to the heating curve of the motor. This would act to open the motor circuit when full load is exceeded. The operation of the protective device is ideal if the motor is allowed to carry small, short and harmless overloads, but is quickly disconnected from the line when an overload has persisted too long. Dual element or time-delay, fuses may provide motor overload protection, but they have the disadvantage of being nonrenewable and must be replaced.

An overload relay is added to the magnetic switch that was shown in figure 3-1. Now it is called a motor starter. The overload relay assembly is the heart of motor protection. A typical solid-state overload relay is shown in figure 3-9. The motor can do no more work than the overload relay permits. Like the dual element fuse, the overload relay has characteristics permitting it to hold in during the motor accelerating period when the inrush current is drawn. Nevertheless,

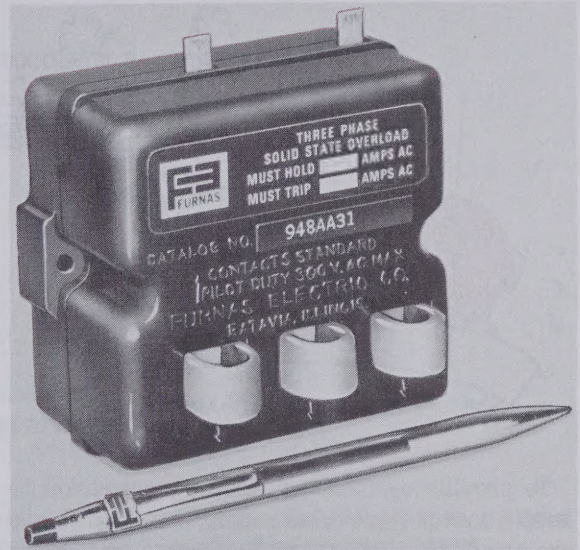
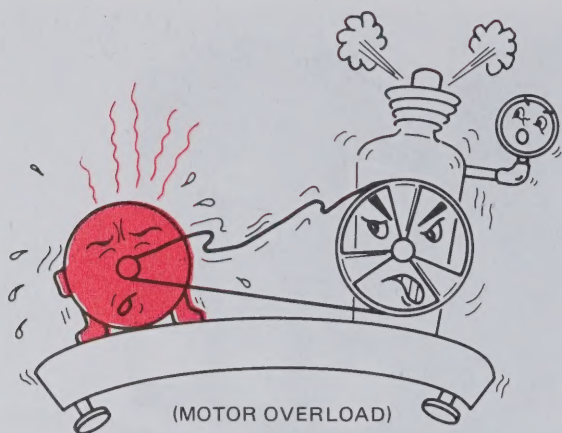


FIG. 3-9 Three-phase solid-state overload relay (Courtesy Furnas Electric Company)

it still provides protection on small overloads above full-load current when the motor is running. Unlike the fuse, the overload relay can be reset. It can withstand repeated trip and reset cycles without need of replacement. It is emphasized that the overload relay does *not* provide short circuit protection. This is the function of overcurrent protective equipment like fuses and circuit breakers, generally located in the disconnecting switch enclosure.

Current drawn by a motor is a convenient and accurate measure of the motor load and motor heating. Therefore, the device used for overload protection, the overload relay, is usually connected with the motor current. It is provided as part of the starter or controller. As the relay carries the motor current, it is affected by that current. If a dangerous overcurrent condition occurs, it operates or trips the relay to open both the control circuit of the magnetic starter and disconnect of the motor from the line; this helps insure the maximum operating life of the motor. In a manual starter, an overload trips a mechanical latch causing the starter contacts to open and disconnect the motor from the line.



To provide *overload* or *running protection* to keep a motor from overheating, overload relays are used on starters to limit the amount of current drawn to a predetermined value. The NEC and local electrical codes determine the size of protective overload relays and heating elements which are properly sized to the motor.

The controller normally is installed in the same room or area as the motor. This makes it subject to the same ambient temperature as the motor. The tripping characteristic of the proper thermal overload relay will then be affected by room temperature exactly as the motor is affected. This is done by selecting a thermal relay element (from a chart provided by the manufacturer) that trips at the danger temper-

ature for the motor windings. When excessive current is drawn, the relay de-energizes the starter and stops the motor.

Overload relays can be classified as being either *thermal*, *electronic* or *magnetic*. Magnetic overload relays react only to current excesses, and are not affected by temperature. As the name implies, *thermal overload relays* depend on the rising ambient temperature and temperatures caused by the overload current to trip the overload mechanism.

Thermal overload relays can be further subdivided into two types — melting alloy and bimetallic.

Electronic or solid-state overload relays, figure 3-9, provide the combination of high-speed trip, adjustability, and ease of installation. They are ideal in many precise applications.

Melting Alloy Thermal Units

The melting alloy assembly consisting of a heater element and solder pot is shown in figure 3-10. The solder pot holds the ratchet wheel in one position. Excessive motor current passes through the heater element and melts an alloy solder pot. Since the ratchet wheel is then free to turn in the molten pool, it trips a set of normally closed contacts which is in the starter control circuit; this stops the motor, figure 3-11. A cooling-off period is required to allow the

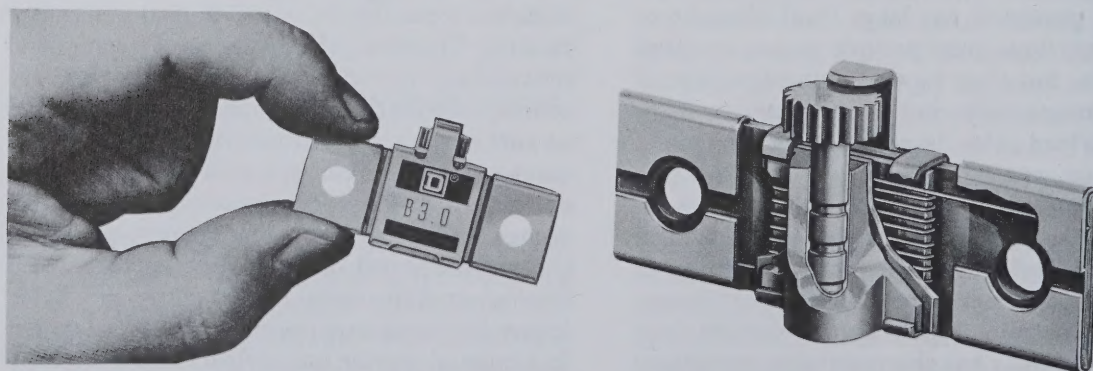


FIG. 3-10 Melting alloy type overload heater. Cutaway view (right) shows construction of heater. (Courtesy Square D Co.)

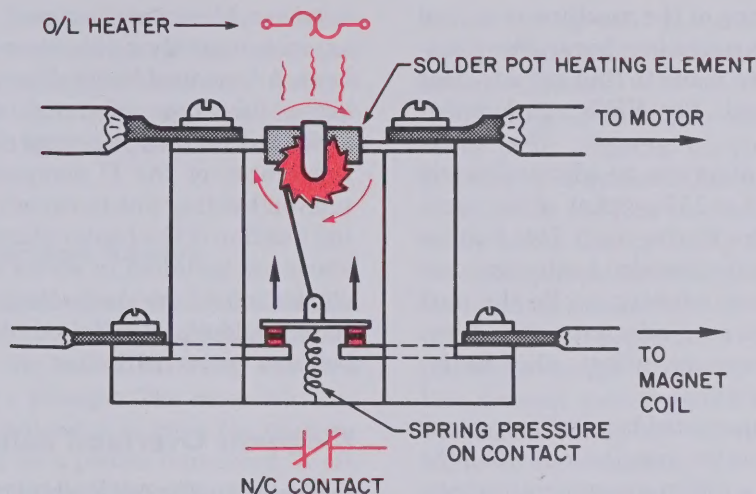


FIG. 3-11 Melting alloy thermal overload relay. Spring pushes contact open as heat melts alloy allowing ratchet wheel to turn freely. Note electrical symbols for overload heater and normally closed control contact.

solder pot to become solid again before the overload relay can be reset and motor service restored.

Melting alloy thermal units are interchangeable. They have a one-piece construction which insures a constant relationship between the heater element and the solder pot. As a result, this unit can be factory calibrated, to make it virtually tamper-proof in the field. These important features are not possible with any other type of overload relay construction. To obtain appropriate tripping current for motors of different sizes, a wide selection of interchangeable thermal units (heaters) is available. They give exact overload protection to motors of different full-load current ratings. Thermal units are rated in amperes and are selected on the basis of motor full-load current. For most accurate overload heater selection, the manufacturer publishes a number of rating tables keyed to the controller in which the overload relay is used. The units are easily mounted into the overload relay assembly and held in place with two screws. Being in series with the motor circuit, the motor will not operate without these heating elements installed in the starter.

Bimetallic Overload Relays

These devices are designed specifically for two general types of application: the automatic reset and bimetallic relay. The automatic reset feature means that the devices can be mounted in locations which are not easily accessible for manual reset operation and may be set in the automatic position by the electrician.

In the automatic reset position, the relay contacts, after tripping, will automatically reclose after the relay has cooled down. This is an advantage when the reset button is hard to reach. Automatic reset overload relays are not normally recommended when used with automatic (two-wire) pilot control devices. With this control arrangement, when the overload relay contacts reclose after an overload trip, the motor will restart. Unless the cause of the overload has been removed, the overload relay will trip again. This event will repeat. Soon the motor will burn out because of the accumulated heat from the repeated high inrush and the overload current. (An overload-indicating light or alarm can be installed to call attention before this happens.) **CAUTION:** The more important point to consider is the possible danger to personnel. This

unexpected restarting of the machine may find the operator or electrician in a hazardous situation, as attempts are made to find out why this machine has stopped. *The NEC prohibits this later installation.*

Most bimetallic relays can be adjusted to trip within a range of 85 to 115 percent of the nominal trip rating of the heater unit. This feature is useful when the recommended heater size may result in unnecessary tripping, while the next larger size will not give adequate protection. Ambient temperatures affect thermally-operated overload relays.

This ambient-compensated bimetallic overload relay is recommended for installations when the motor is located in a different ambient temperature from the motor starter. If the controller is located in a changing temperature, the overload relay can be adjusted to compensate for these temperature changes. This thermal overload relay is always affected by the surrounding temperature. If a standard thermal overload relay were used, it would not trip consistently at the same level of motor current whenever the controller temperature changed.

The tripping of the control circuit in the bimetallic relay results from the difference of expansion of two dissimilar metals fused

together. Movement occurs if one of the metals expands more than the other when subjected to heat. A U-shaped bimetallic strip is used to calibrate this type of relay, figure 3-12. The U-shaped strip and a heater element inserted in the center of the U compensate for possible uneven heating due to variations in the mounting location of the heater element. Since a motor starter is installed in series with the load, the starter must have the heating element (bimetallic and solder pot) installed in the overload relay before a motor will start.

Magnetic Overload Relays

The magnetic overload relay coil is connected in series directly with the motor or is indirectly connected by current transformers (as in circuits with large motors). As a result, the coil of the magnetic relay must be wound with wire large enough in size to pass the motor current. These overload relays operate by current intensity and not heat.

Magnetic overload relays are used when an electrical contact must be opened or closed as the actuating current rises to a certain value. In some cases, the relay may also be used so that it is actuated when the current falls to a certain

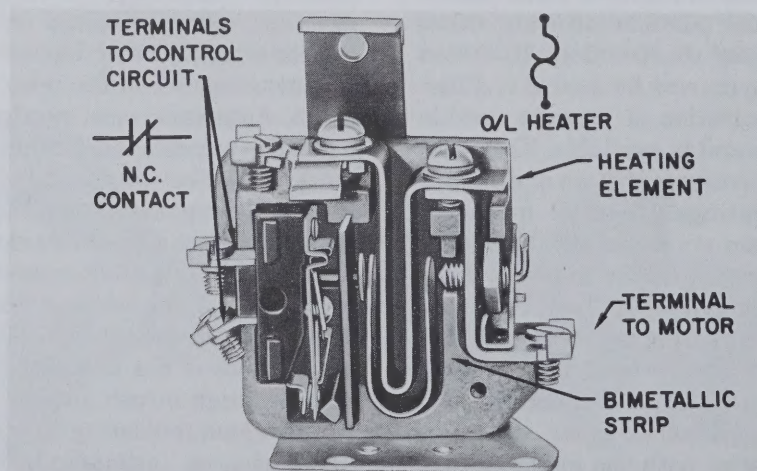


FIG. 3-12 Cutaway view showing construction of bimetallic overload relay and electrical symbols representing elements of the relay (Courtesy Square D Co.)

value. Magnetic overload relays are used to protect large motor windings against continued overcurrent. Typical applications are: to stop a material conveyor when conveyors ahead become overloaded, and to limit torque reflected by the motor current.

Time Limit Overload Relays

Time delay overload relays, figure 3-13, make use of the oil dashpot principle. Motor current passing through the coil of the relay exerts a magnetic pull on a plunger. The magnetic flux set up inside the coil tends to raise the plunger which is attached to a piston immersed in oil. As the current increases in the relay coil, so does the magnetic flux. The force of gravity is overcome and the plunger and piston move upward. During this upward movement, oil is forced through bypass holes in the piston. As a result, the operation of the contacts is delayed. A valve disc is turned to open or close bypass holes of various sizes in the piston. This action changes the rate of oil flow and so adjusts the time delay factor. The rate of upward travel — of the core and piston — depends directly upon the degree of overload. The greater the current load, the

faster the upward movement. As the rate of upward movement increases, the relay tripping time decreases.

This inverse time characteristic prevents the relay from tripping on the normal starting current or on harmless momentary overloads. In these cases, the line current drops to its normal value before the operating coil is able to lift the core and piston far enough to operate the overload control contacts. However, if the overcurrent continues for a prolonged period, the core is pulled far enough to operate the contacts. As the line current increases the relay tripping time decreases. Tripping current adjustment is achieved by adjusting the plunger core with respect to the overload relay coil. Quick tripping is obtained through the use of a light trade dashpot oil and by adjustment of the oil bypass holes.

A valve in the piston allows almost instantaneous resetting of the circuit to restart the motor. The current must then be reduced to a very low value before the relay will reset. This action is accomplished automatically when the tripping of the relay disconnects the motor from the line. Magnetic overload relays are available with either automatic reset contacts or hand reset contacts.

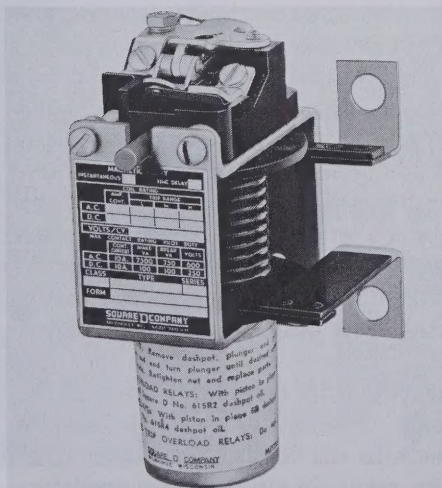


FIG. 3-13 Time limit overload magnetic relay
(Courtesy Square D Co.)

Instantaneous Trip Current Relays

Instantaneous trip current relays are used to take a motor off the line as soon as a predetermined load condition is reached. For example, when a blockage of material on a woodworking machine causes a sudden high current, an instantaneous trip relay can cut off the motor quickly. After the cause of the blockage is removed, the motor can be restarted immediately because the relay resets itself as soon as the overload is removed. This type of relay is also used on conveyors to stop the motor before mechanical breakage results from a blockage.

The instantaneous trip current relay does not have the inverse time characteristic. Thus, it must not be used in ordinary applications requiring an overload relay. The instantaneous trip

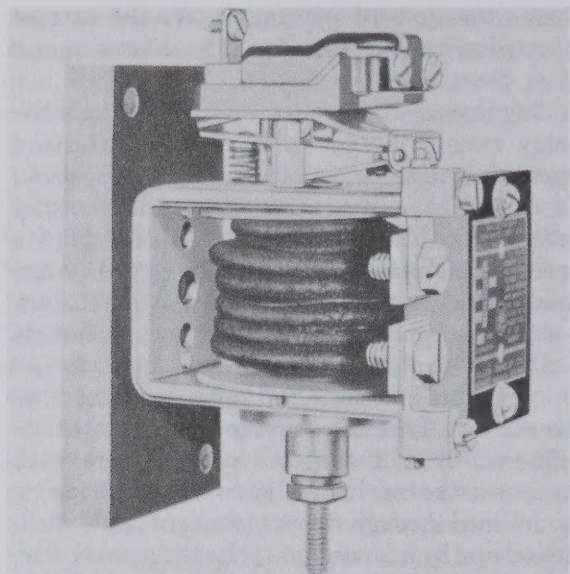


FIG. 3-14 Instantaneous trip current relay (Courtesy Allen-Bradley Co.)

current relay should be considered as a special-purpose relay.

The operating mechanism of the trip relay in figure 3-14 consists of a solenoid coil through which the motor current flows. There is a movable iron core within the coil. Mounted on top of the solenoid frame is a snap-action precision switch which has connections for either a normally open or normally closed contact. The motor current exerts a magnetic pull upward on the iron core. Normally, however, the pull is not sufficient to lift the core. If an overcurrent condition causes the core to be lifted, the snap-action precision switch is operated to trip the control contact of the relay.

The tripping value of the relay can be set over a wide range of current ratings by moving the plunger core up and down on the threaded stem. As a result, the position of the core in the solenoid is changed. By lowering the core, the magnetic flux is weakened and a higher current is required to lift the core and trip the relay.

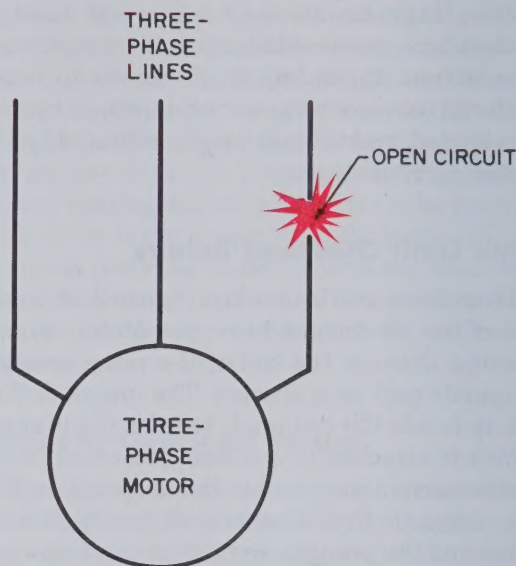


FIG. 3-15 A single-phase condition: two high currents, one zero current

Number of Overload Relays Needed to Protect a Motor

There may be more three-phase motor starters with two overload relays already installed than starters with three overload relays. However, this trend will reverse due to a National Electrical Code requirement of three overload relays for three-phase starters on new installations.

A balanced supply voltage must be maintained for all polyphase load installations.

A single-phase load on a three-phase circuit can produce serious unbalanced motor currents. A large three-phase motor on the same feeder with a small three-phase motor may not be protected if a single-phase condition occurs, figure 3-15.

A defective line fuse, an open “leg” through a circuit breaker, a loose or broken wire anywhere in the conduit system or in a motor lead can result in single-phase operation. This will show up as a sluggish, hot-running motor. The motor will not start at all but will produce

a distinct magnetic hum when it is energized. The three-phase motor may continue to operate (at reduced torque) when single phasing occurs. But once stopped, it will not restart. This is also a sign of a single-phase condition in a three-phase motor.

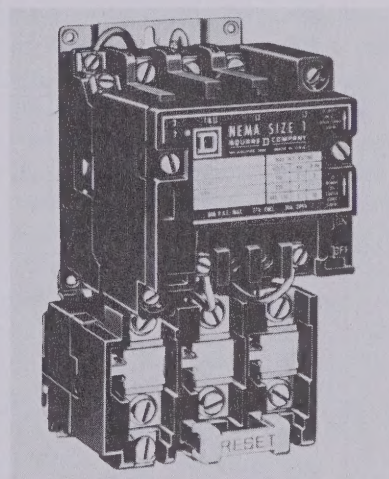
Unbalanced single-phase loads on three-phase panel boards must be avoided. Problems may occur on distribution systems where one or more large motors may feed back power to smaller motors under open-phase conditions.

THE AC MAGNETIC STARTER

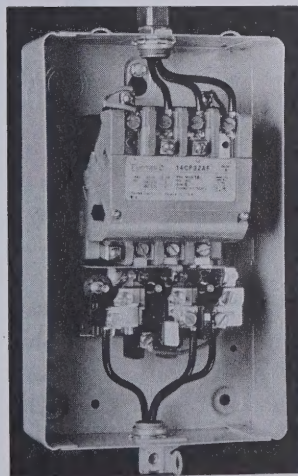
An ac three-phase magnetic motor starter is shown in figure 3-16(A). It is also called a full-voltage or across-the-line starter.

The overload reset button can be seen on the bottom center of the photo. It is usual practice to build motor controllers with manual reset overload relays. This encourages the machine operator to remove the cause of the overload. It also enforces at least a little cooling off period after tripping.

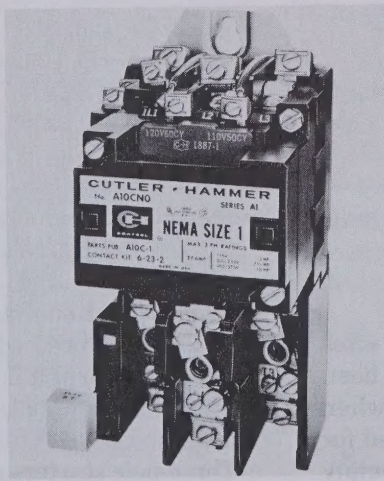
Three overload heating elements for three-phase operation are installed in the relays above the reset button. The contacts are under the insulating arcing block cover, easily accessible for inspection with the removal of two screws. The starter must be mounted in an enclosure for installation as in figure 3-16(B). Another type of three-phase, ac magnetic motor starter is shown in figure 3-16(C). A typical, fast terminal wiring method is shown in figure 3-16(D).



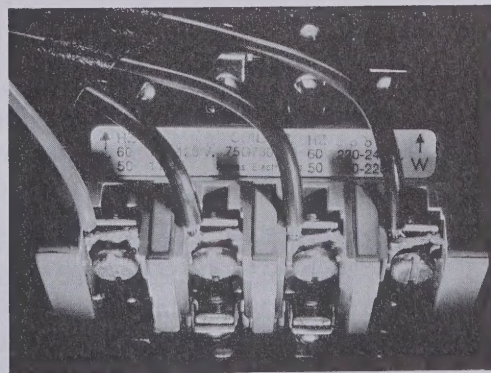
(A)



(B)



(C)



(D)

FIG. 3-16 Three-phase ac magnetic motor starters: (A) Courtesy Square D Co., (B) Courtesy Furnas Electric Company, (C) Courtesy EATON Corp., Cutler-Hammer Products, (D) Courtesy Furnas Electric Company.

TABLE 3-1 Standard Motor Starter Sizes and Ratings

*NEMA SIZE (EEMAC SIZE)	LOAD VOLTS	MAXIMUM HORSEPOWER RATING — NONPLUGGING AND NONJOGGING DUTY		*NEMA SIZE (EEMAC SIZE)	LOAD VOLTS	MAXIMUM HORSEPOWER RATING — NONPLUGGING AND NONJOGGING DUTY	
		SINGLE PHASE	POLY- PHASE			SINGLE PHASE	POLY- PHASE
00	115	1/3	...	3	115	7 1/2	...
	200 (208)	...	1 1/2		200 (208)	...	25
	230	1	1 1/2		230	15	30
	460	...	2		460	...	50
	575	...	2		575	...	50
0	115	1	...	4	200 (208)	...	40
	200 (208)	...	3		230	...	50
	230	2	3		460	...	100
	460	...	5		575	...	100
	575	...	5				
1	115	2	...	5	200 (208)	...	75
	200 (208)	...	7 1/2		230	...	100
	230	3	7 1/2		460	...	200
	460	...	10		575	...	200
	575	...	10				
2	115	3	...	6	200 (208)	...	150
	200 (208)	...	10		230	...	200
	230	7 1/2	15		460	...	400
	460	...	25		575	...	400
	575	...	25				
				7	230	...	300
					460	...	600
					575	...	600
				8	230	...	450
					460	...	900
					575	...	900

*In Canada, the Electrical and Electronic Manufacturers Association of Canada use the same sizes, and they are defined as EEMAC size numbers.

Starter Sizes

Magnetic starters are available in many sizes as shown in Table 3-1. Each size has been assigned a horsepower rating that applies when the motor used with the starter is operated for normal starting duty. All starter ratings comply with the National Electrical Manufacturers Association Standards. The capacity of a starter is determined by the size of its contacts and the

wire cross-sectional area. The size of the power contacts is reduced when the voltage is doubled because the current is halved for the same power ($P = 1 \times E$). Power circuit contacts handle the motor load.

Three-pole starters are used with motors operating on three-phase, three-wire ac systems. Two-pole starters are used for single-phase motors.

The number of *poles* refers to the power contacts, or the motor load contacts, and does not include control contacts for control circuit wiring.

AC COMBINATION STARTERS

The circuit breakers and fuses of the motor feeders and branch circuits are normally selected for overcurrent, short-circuit, or ground-fault protection.

With minor exceptions, the National Electrical Code and some local codes also require that every motor has a disconnect means. This means may be an attachment cord cap and receptacle, a nonfusible isolation disconnect safety switch, a fusible disconnect motor switch or a combination starter. A combination starter (figure 3-17)

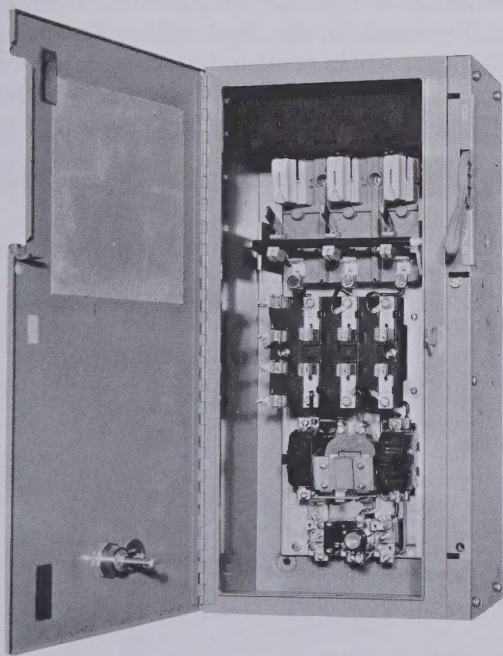


FIG. 3-17 Combination starter with fuses removed. Disconnect switch must be open before door can be opened.

consists of an across-the-line starter and a disconnect means wired together in a common enclosure. Combination starters may have a blade-type disconnect switch, either fusible or nonfusible, or a thermal-magnetic trip circuit breaker. The starter may be controlled remotely with push buttons or selector switches, or these devices may be installed in the cover of the starter enclosure. The combination starter takes little mounting space and makes compact electrical installation possible.

A combination starter provides safety for the operator because the cover of the enclosure is interlocked with the external, operating handle of the disconnecting means. The door cannot be opened while the disconnecting means is closed. When the disconnecting means is open, all parts of the starter are accessible; however, the hazard is reduced since the readily accessible parts of the starter are not connected to the power line. This safety feature is not available on separately enclosed starters. In addition, the starter enclosure is provided with a means for padlocking the disconnect in the OFF position. Controller enclosures are available for every purpose and application.

Protective Enclosures

The selection and installation of the correct enclosure can contribute to useful, safe service and freedom from trouble in operating electromagnetic control equipment.

An enclosure is the surrounding controller case, cabinet or box. Generally, this electrical equipment is enclosed for one or more of the following reasons:

- (A) To shield and protect workers and other personnel from accidental contact with electrically live parts, thereby preventing electrocution.
- (B) To prevent other conducting equipment from coming into contact with live electrical parts, thereby preventing unnecessary electrical outages and indirectly protecting personnel from electrical contact.

- (C) To protect the electrical controller from harmful atmospheric or environmental conditions, such as the presence of dust or moisture, to prevent corrosion and interference of operation.
- (D) To contain the electrical arc of switching within the enclosure, to prevent explosions and fires which may occur with flammable gases or vapors within the area.

You may readily understand why some form of enclosure is necessary and required. The most frequent requirement is usually met by a general-purpose, sheet steel cabinet. The conduit is installed with lock-nuts and bushings. The presence of dust, moisture, or explosive gases often makes it necessary to use a special enclosure to protect the controller from corrosion or the surrounding equipment from possible explosions. Conduit access is through threaded openings, hubs, or flanges. In selecting and installing control apparatus, it is necessary to carefully consider the conditions under which the apparatus must operate. There are many applications where a general-purpose sheet steel enclosure does not give sufficient protection.

Water-tight and dust-tight enclosures are used for the protection of control apparatus. Dirt, oil, or excessive moisture are destructive to insulation and frequently form current-carrying paths that lead to short circuits or grounded circuits.

Special enclosures for hazardous locations are used for the protection of life and property. Explosive vapors or dusts exist in some departments of many industrial plants as well as in grain elevators, refineries, and chemical plants. The National Electrical Code and local codes describe hazardous locations. The Underwriters' Laboratories have defined the requirements for protective enclosures according to the hazardous conditions. The National Electrical Manufacturers Association (NEMA) has standardized enclosures from these requirements. Some examples are as follows.

General-Purpose enclosures (NEMA 1) These enclosures are constructed of sheet steel, and are

designed primarily to prevent accidental contact with live parts. Covers have latches with provisions for padlocking, figure 3-18. Enclosures are intended for use indoors, in areas where unusual service conditions do not exist. They do provide protection from light splash, dust and falling debris such as dirt.

Watertight enclosures (NEMA 4) These enclosures are made of cast construction or of sheet metal of suitable rigidity and are designed to pass a hose test with no leakage of water. Watertight enclosures are suitable for outdoor applications, on ship docks, in dairies, breweries, and other locations where the apparatus is subjected to dripping or splashing liquids, figure 3-19. Enclosures which meet requirements for more than one NEMA type may be designated by a combination of type numbers, for example, Type 3-4, dust-tight and water-tight.

Dust-tight enclosures (NEMA 12) These enclosures are constructed of sheet steel and are provided with cover gaskets to exclude dust, lint, dirt, fibers and flyings. Dust-tight enclosures are suitable for use in steel and knitting mills, coke plants, and similar locations where

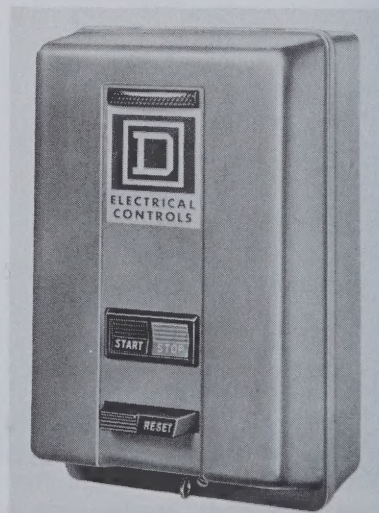


FIG. 3-18 General-purpose enclosure (NEMA 1) (Courtesy Square D Co.)

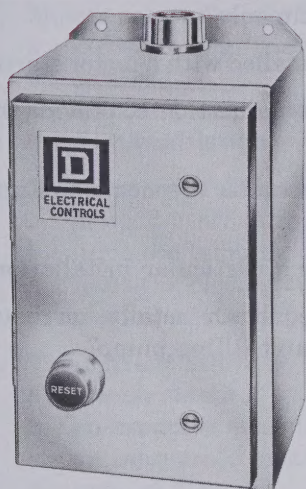


FIG. 3-19 Watertight enclosure (NEMA 4) (Courtesy Square D Co.)

nonhazardous dusts are present. Mounting is by means of outside flanges or mounting feet.

Hazardous Locations (NEMA 7) Class 1 enclosures are designed for use in hazardous locations where atmospheres containing gaso-

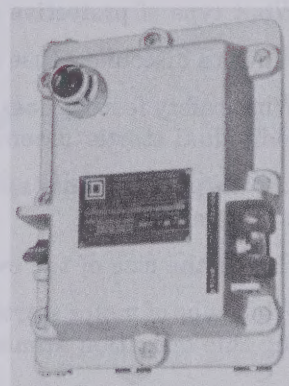


FIG. 3-20 Hazardous location enclosure (NEMA 7) (Courtesy Square D Co.)

line, petroleum, naphtha, alcohol, acetone, or lacquer solvent vapors are present or may be encountered. Enclosures are heavy, grey iron castings, machined to provide a metal-to-metal seal, figure 3-20.

NOTE: Applicable and enforced National, State, or local electrical codes and ordinances should be consulted to determine the safe way to make any installation.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What is a magnetic line voltage motor starter?
2. How many poles are required on motor starters for the following motors: (a) 240-volt, single-phase induction motor, (b) 440-volt, three-phase induction motor?
3. If a motor starter is installed according to directions but will not start, what is a common cause for the failure to start?
4. Using the time limit overload or the dashpot overload relay, how are the following achieved: time delay characteristics; tripping current adjustments?
5. What is meant by chattering of an ac magnet?
6. What is the phase relationship between the flux in the main pole of a magnet and the flux in the shaded portion of the pole?
7. In what devices is the principle of the shaded pole used?
8. What does the electrician look for to remedy the following conditions: loud or noisy hum; chatter?

9. What type of protective enclosure is used most commonly?
10. Why is a disconnect fuse switch or circuit breaker installed with a motor starter?
11. What safety feature does the type of assembly given in question 10 provide that individual starter assemblies do not?
12. List the probable causes if the armature does not release after the magnetic starter is de-energized.
13. How is the size of the overload heaters selected for a particular installation?
14. What type of motor starter enclosure is recommended for an installation requiring safe operation around an outside flammable paint filling pump?

Select the *best* answer for each of the following.

15. The magnetic starter is held closed
 - a. mechanically
 - b. by 15% undervoltage
 - c. by 15% overvoltage
 - d. magnetically
16. When a motor starter coil is de-energized
 - a. the contacts stay closed
 - b. it is held closed mechanically
 - c. gravity and spring tension open contacts
 - d. it must cool for a restart
17. An ac magnet may hum excessively due to
 - a. improper alignment
 - b. foreign matter between contact surfaces
 - c. loose laminations
 - d. all of these
18. Ac magnets are made of *laminated* iron
 - a. for better induction
 - b. to reduce heating effect
 - c. for ac and dc use
 - d. to prevent chattering
19. The purpose of overload protection on a motor is to protect the
 - a. motor from sustained overcurrents
 - b. wire from high currents
 - c. motor from sustained overvoltage
 - d. motor from short circuits
20. The number of magnetic starter poles refers to
 - a. the number of power load contacts
 - b. the number of control contacts
 - c. the number of north and south poles
 - d. all of these

21. Motors may burn out because of
 - a. excessive heat from within and without
 - b. overloads
 - c. high ambient temperatures
 - d. poor ventilation
22. The purpose of a shading coil on an ac electromagnetic pole tip is to
 - a. prevent overheating of the coil
 - b. limit the tripping current
 - c. limit the closing current
 - d. prevent chattering
23. The current drawn by a motor is
 - a. low on starting
 - b. an accurate measurement of motor load
 - c. an inaccurate measurement of motor load
 - d. none of these
24. Thermal overload relays depend on
 - a. rising ambient and temperatures due to current overload
 - b. heavy mechanical loads
 - c. heavy electrical loads
 - d. rising starting currents
25. The thermal relay heating element is selected
 - a. 15% under voltage
 - b. 10% over voltage
 - c. from a table by the manufacturer
 - d. by ambient temperature
26. When the reset button does not re-establish the control circuit after an overload, the probable cause is
 - a. the overload heater is too small
 - b. the overload trip has not cooled sufficiently
 - c. the auxiliary contacts are defective
 - d. the overload heater is burned out
27. If an operator pushes a start button on a three-phase induction motor and the motor starts to hum, but not run, the probable trouble is
 - a. one fuse is blown and the motor is single phasing
 - b. the overload trip needs resetting
 - c. the auxiliary contact is shorted
 - d. one phase is grounded
28. A combination starter provides
 - a. disconnecting means
 - b. overload protection
 - c. short circuit protection
 - d. all of these

SECTION TWO

A series of ten thin, horizontal white lines stacked vertically, serving as a decorative separator between the section title and the main title.

CIRCUIT LAYOUT, CONNECTIONS AND SYMBOLS

UNIT 4 Symbols

UNIT 5 Interpretation and Application of Simple Wiring and
Elementary Diagrams

UNIT 4 Symbols

Objectives After studying this unit, the student will be able to:

- Identify common electrical symbols used in motor control diagrams
- Use electrical symbols in drawing schematic and wiring diagrams
- Draw and define supplementary contact symbols

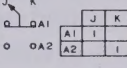
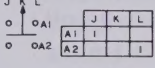
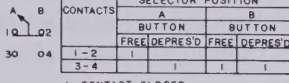
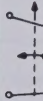
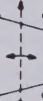
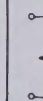
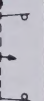
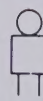
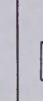
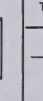
If the directions for wiring electrical equipment are written without the use of diagrams, or if diagrams are used but must show each device as it actually appears, then the work and time involved both in preparing the directions and in installing the equipment will be very expensive. Therefore, symbols — a form of pictorial shorthand — are used rather than pictures of electrical equipment to show how separate pieces of electrical equipment are connected in a circuit. Because the symbols may not be similar to the physical appearance of the devices they represent, many symbols must be memorized.

Standard symbols for electrical components have been established, figure 4-1. However, their use is not completely universal and some industries use variations of the basic symbols. In spite of the lack of standardization, knowledge of the symbols presented in this unit will give you a firm basis for interpreting variations found in the field. A thorough knowledge of the standard symbols will help you to read and draw electrical diagrams.

The symbols in figure 4-1 conform to standards established by the National Electrical Manufacturers Association (NEMA). Where NEMA

SWITCHES							
DISCONNECT	CIRCUIT INTERRUPTER	CIRCUIT BREAKER W/THERMAL O.L.	CIRCUIT BREAKER W/MAGNETIC O.L.	CIRCUIT BREAKER W/THERMAL AND MAGNETIC O.L.	LIMIT SWITCHES		FOOT SWITCHES
					NORMALLY OPEN	NORMALLY CLOSED	
PRESSURE & VACUUM SWITCHES		LIQUID LEVEL SWITCH		TEMPERATURE ACTUATED SWITCH		FLOW SWITCH (AIR, WATER, ETC.)	
N.O.	N.C.	N.O.	N.C.	N.O.	N.C.	N.O.	N.C.

FIG. 4-1 Standard wiring diagram symbols

FUSE		STANDARD DUTY SELECTOR		HEAVY DUTY SELECTOR										
		2 POSITION		2 POSITION		3 POSITION		2 POS SEL PUSH BUTTON						
				 1- CONTACT CLOSED		 1- CONTACT CLOSED		 1-CONTACT CLOSED						
		3 POSITION												
		PUSH BUTTONS										PILOT LIGHTS		
MOMENTARY CONTACT										MAINTAINED CONTACT		INDICATE COLOR BY LETTER		
SINGLE CIRCUIT		DOUBLE CIRCUIT		MUSHROOM HEAD	WOBBLE STICK	ILLUMINATED	TWO SINGLE CKT.		ONE DOUBLE CKT.		NON PUSH-TO-TEST	PUSH-TO-TEST		
NO	NC	NO	NC											
														
CONTACTS										COILS		OVERLOAD RELAYS		INDUCTORS
INSTANT OPERATING				TIMED CONTACTS - CONTACT ACTION RETARDED WHEN COIL IS				SHUNT		SERIES		WIREWOUND	IRON CORE	
WITH BLOWOUT		WITHOUT BLOWOUT		ENERGIZED		DE-ENERGIZED								
NO	N.C.	NO	N.C.	NO	N.C.	NO	N.C.							
														
TRANSFORMERS				A C MOTORS				D C MOTORS				COMM OR COMPENS FIELD		
AUTO	IRON CORE	AIR CORE	CURRENT	DUAL VOLTAGE	SINGLE PHASE	3 PHASE SQUIRREL CAGE	WOUND ROTOR	ARMATURE	SHUNT FIELD	SERIES FIELD				
									 (SHOW 4 LOOPS)	 (SHOW 3 LOOPS)	 (SHOW 2 LOOPS)			
WIRING				CONNECTIONS		RESISTORS			CAPACITORS					
NOT CONNECTED	CONNECTED	POWER	CONTROL	WIRING TERMINAL	MECHANICAL	FIXED	ADJ BY FIXED TAPS	RHEOSTAT, POT OR ADJ TAP		FIXED				
														
				GROUND	MECHANICAL INTERLOCK	HEATING ELEMENT								
														
SPEED (PLUGGING)		ANTI-PLUG		BELL	BUZZER	HORN SIREN, ETC	METER	METER SHUNT	HALF WAVE RECTIFIER	FULL WAVE RECTIFIER	BATTERY			
														
SEMICONDUCTORS										LIGHT EMITTING DIODE				
DIODE				SILICON CONTROLLED RECTIFIER (SCR)										
														

standards do not exist, American Standards Association (ASA) standards are used.

It is recommended that you refer frequently to the symbol list while working through each unit until you are thoroughly familiar with all of the symbols.

EXPLANATION OF COMMON SYMBOLS

The control circuit line diagram of figure 4-2 shows the symbols of each device used in the circuit. The diagram indicates the function of each device. The push-button station wiring diagram on the right of figure 4-2 represents the physical control station and shows the relative

position of each device, the internal wiring, and the connections with the motor starter.

Some of the symbols in figure 4-1 were presented earlier in this text for selected control pilot devices. The balance of the symbols used throughout the text and in industry are contained in typical circuit diagrams on the following pages.

Refer to figure 4-1. The disconnect switch shown is used to disconnect live equipment from the line voltage. This action is usually done with the equipment unloaded. The load may be interrupted by using contactors, motor starters, or circuit interrupters such as circuit breakers.

Machine operators often find that a foot switch is provided. The use of the foot switch frees the operator's hands. The switch mechanism is

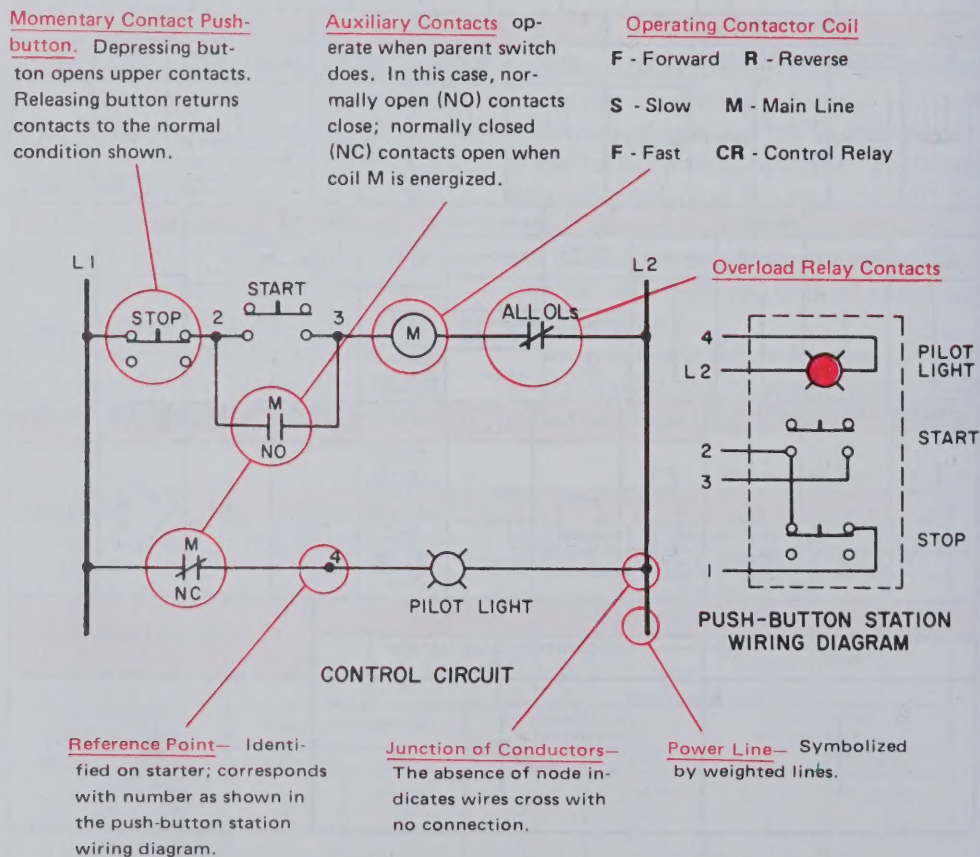


FIG. 4-2 Control circuit components

usually a heavy-duty, double-break, normally open or closed switch in a rugged enclosure with a broad mushroom-like metallic pedal or foot operator. This type of switch may be connected by a portable cord or wired in solid, in a stationary position near the machine to be controlled.

The wobble stick push button is controlled by a stem which can be operated from any direction. It is so constructed for fast and easy access by a production machine operator.

The maintained contact push buttons are mechanically held in the selected position.

The push to test pilot light is used to ensure that the lamp and circuit are OK. In the push position it is placed across the control voltage. Otherwise, it may be connected so that it will indicate when some machine or pump motor is on or off.

The timed contacts are described in unit 8, Timing Relays. Note that there is a time delay in the contact action when the relay coil is energized (on delay). In a different contact

arrangement, there is also a time delay when the coil is de-energized (off delay).

A shunt coil is connected with the full voltage applied. A series coil is connected in series with a load or the full current.

In drawing wiring diagrams, it is not an accepted practice to "jump" a wire. Wires are shown as crossing each other and, unless specified otherwise, are not connected. If a wire is to be connected, a quick method is to show it with a connection node or dot.

Mechanical connections are shown with straight broken lines (they are insulated, non-current carrying parts). One example is when two contacts are operated at the same time on a push button.

The speed plugging and antiplugging switch symbol will be shown in use later in the text.

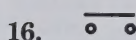
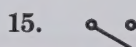
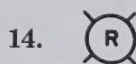
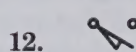
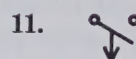
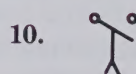
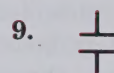
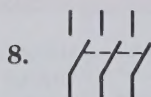
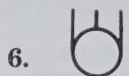
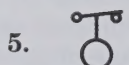
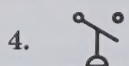
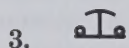
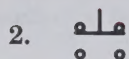
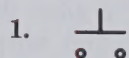
Figure 4-3 defines abbreviations commonly used in wiring prints and specifications. The symbols further illustrate descriptions of the abbreviations.

SPST, N. O.		SPST N. C.		SPDT		TERMS
SINGLE BREAK	DOUBLE BREAK	SINGLE BREAK	DOUBLE BREAK	SINGLE BREAK	DOUBLE BREAK	
DPST, 2 N. O.		DPST, 2 N. C.		DPDT		
SINGLE BREAK	DOUBLE BREAK	SINGLE BREAK	DOUBLE BREAK	SINGLE BREAK	DOUBLE BREAK	
						SPST – SINGLE POLE SINGLE THROW
						SPDT – SINGLE POLE DOUBLE THROW
						DPST – DOUBLE POLE SINGLE THROW
						DPDT – DOUBLE POLE DOUBLE THROW
						N. O. – NORMALLY OPEN
						N. C. – NORMALLY CLOSED
SYMBOLS FOR STATIC PROXIMITY SWITCHING CONTROL DEVICES						
LIMIT SW. NC	LIMIT SW. NO	INPUT “COIL”	OUTPUT NC	METHOD OF SWITCHING ELECTRICAL CIRCUITS WITHOUT THE USE OF CONTACTS= STATIC CONTROL. THE SYMBOL SHOWN IN THE TABLE ARE USED BY ENCLOSING THEM IN A DIAMOND SHAPE.		

FIG. 4-3 Supplementary contact symbols

STUDY ■ DISCUSSION ■ TEST QUESTIONS

Identify the following symbols



UNIT 5 Interpretation and Application of Simple Wiring and Elementary Diagrams

Objectives After studying this unit, the student will be able to:

- Draw an elementary line diagram using a wiring diagram as a reference
- Describe the different advantages of two- and three-wire control
- Connect motor starters with two- and three-wire control
- Identify common terminal markings
- Read and use target tables
- Connect drum reversing controllers
- Interpret motor nameplate information
- Connect dual-voltage motors

LINE DIAGRAMS AND WIRING DIAGRAMS

Most electrical circuits can be represented by two types of diagrams: a wiring diagram and a line diagram. *Wiring diagrams* include all of the devices in the system and show the physical relationships between the devices. All poles, terminals, contacts and coils are shown on each device. These diagrams are particularly useful in wiring circuits because the connections can be made exactly as they appear on the diagram, a wire for every line. A wiring diagram gives the necessary information for the actual wiring of a circuit and provides a means of physically tracing the wires for troubleshooting purposes or when normal preventative maintenance is neces-

sary. In other words, the actual physical installation and the wiring diagram coincide as far as the locations of the devices and wiring are concerned.

The wiring diagram is quite often such a maze of lines that it may be nearly impossible to determine the electrical sequence of operation of the circuits shown. For this reason, a rearrangement of the circuit elements is made to form what is called a *line diagram*. Line diagrams, also called elementary, schematic and ladder diagrams, are widely used in industry. It is a decided advantage to the electrician to learn to use these diagrams.

The line diagram also represents the electrical circuit, but does so in the simplest manner possible. No attempt is made to show the vari-

ous devices in their actual physical positions. All control devices are shown located between vertical lines that represent the source of control power. Circuits are shown connected as directly as possible from one of the source lines horizontally — through contacts and current consuming devices — to the other source line. All connections are made so that the functions and sequence of operations of the various devices and circuits can be traced easily. The schematic diagram is invaluable in troubleshooting because it shows the effect that opening or closing various contacts have on other devices in the circuit. The schematic diagram attempts to convey as much information as possible with the least amount of confusion. It shows you in the simplest manner how an electrical control system should work.

Any single operation of a piece of electrical equipment is usually not complicated. However, when a sequence of operations to be completed by electrical means depends upon the present, previous, or subsequent operations of several other pieces of equipment, the number of operations forms a complex system which may be difficult to understand. The line diagram reduces the necessary information to the simplest possible form to help the electrician understand the operation of the total control system.

Figure 5-1 illustrates the simplicity of an elementary or schematic diagram. Note how easy it is to trace through the circuit: when the disconnect switch is closed, current flows through the only complete path — L1 down through the normally closed contact CR, through the red pilot lamp to L2. When the normally open push button is closed, CR coil is energized through the complete circuit to L2 from L1. When the control relay is energized, it instantly closes the normally open CR contact to energize the green indicating lamp. At the same time, it opens normally closed contact CR, interrupting the circuit to the red lamp. When the push button is released, the red lamp is again lit and the green lamp goes out because

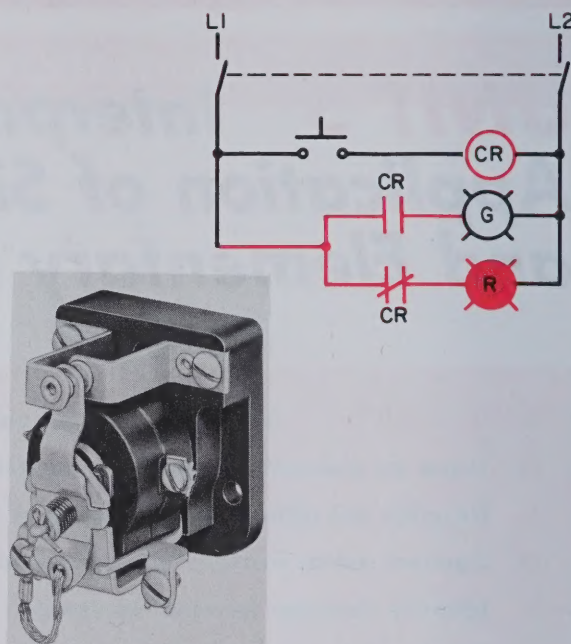


FIG. 5-1 A S.P.D.T. control relay and its schematic diagram

the coil is now de-energized. The normally open CR contact opens and normally closed CR contact closes.

Study figure 5-2 to become familiar with a motor starter as it is represented by a *wiring diagram*. The principal parts of the starter are labeled on the diagram so that a comparison can be made with the actual starter. This study should help you to visualize the starter when viewing a wiring diagram, and will help in making the correct connections when the starter is actually wired. Note that the wiring diagram shows as many parts as possible in their proper relative positions. It is not necessary to show the armature and crossbar or the overload reset mechanism of the starter in the wiring diagram since these parts are not involved in the actual wiring. The *control circuit* consists of the coil, the contacts of the overload relays, and the coil-holding contact for the control circuit. The *power circuit* consists of the main contacts and the overload heaters to the motor. Note the heavier lines

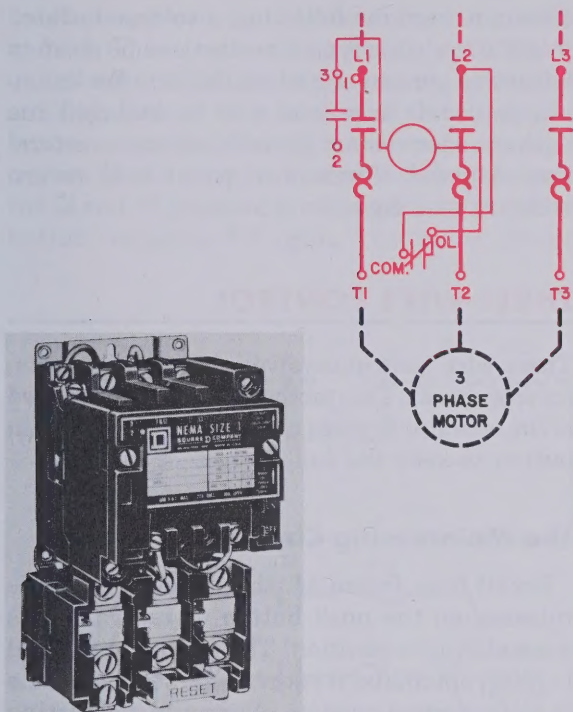


FIG. 5-2 Ac magnetic motor starter (Courtesy Square D Co.)

used for the power circuit. The broken lines show where the power lines and motor leads connect to the starter.

The wiring diagram in figure 5-2 represents a size one motor starter. Other starter sizes have similar diagrams and are wired in a similar manner. Some of the connections, however, may not have the same physical locations on the starters.

Figure 5-3 is an elementary or line diagram of the starter shown in figure 5-2. In many cases, the line diagram does not show the power circuit to the motor because of its simplicity. Note that the line 1 (L1) circuit is completed to the motor (when the coil is energized) closing main contact (M) and the overload heater to terminal 1 (T1) of the motor. All of the M contacts close simultaneously when the M coil is energized. The motor then starts with the applied line voltage.

The control wiring of the starter is shown in solid lines, figure 5-3(b). This completes the wiring of the actual starter. The external wiring completed by the electrician in the field is shown by broken lines. Note how the control wiring is rearranged to form one horizontal path from line

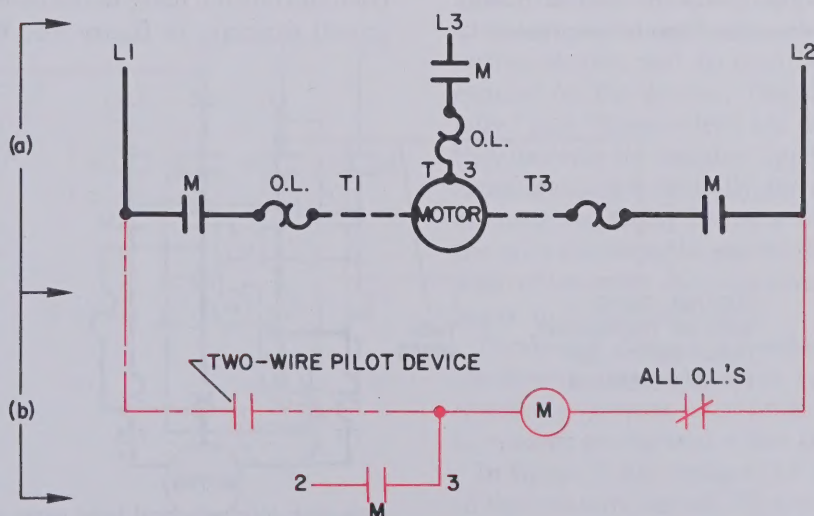


FIG. 5-3 Line diagram of starter shown in figure 5-2: (a) Line diagram showing the simplicity of the power circuit for the line voltage starter; (b) Completed control wiring elementary style. Broken lines and motor are external field wiring that completes the circuit.

1 (L1) to line 2 (L2). This figure shows how the control wiring diagram is converted in appearance to a line diagram. Although the drawings differ, they are the same electrically. In general, it is easier to trace the operation of the starter by viewing the line drawing than it is to use the wiring diagram of the same starter. Compare the two diagrams carefully. You may be required to convert a complex wiring diagram to an elementary diagram to determine how a machine operates.

TWO-WIRE CONTROL

Two-wire control provides no-voltage release or low-voltage release. Two-wire control of a starter means that the starter drops out when there is a voltage failure and picks up as soon as the voltage returns. In figure 5-4, the pilot device is unaffected by the loss of voltage. Its contact remains closed, ready to carry current as soon as line voltage returns to normal. This form of control is used frequently to operate supply and exhaust blowers and fans.

Two-wire control is also shown in schematic form in figure 5-3(b). Two-wire control means that an operator does not have to be present to

restart a machine following a voltage failure.

CAUTION: this type of restart can be a safety hazard to personnel and machinery. For example, materials in process may be damaged due to the sudden restart of machines upon restoration of power. (Remember, power may return without warning.)

THREE-WIRE CONTROL

Three-wire control involves the use of a *maintaining circuit*. This method eliminates the need of the operator to press continuously on the push button to keep the coil energized.

The Maintaining Circuit

Recall from figure 5-1 that when pressure is released on the push button, it returns to its normally open position. The circuit to the coil is interrupted and it returns the relay contacts to their normal position. Normally, in starting a motor, it is desirable to energize the motor starter coil by pressing a button and then to keep the coil energized after the pressure is released from the button. Refer to the elementary control circuit diagram in figure 5-5. When the start

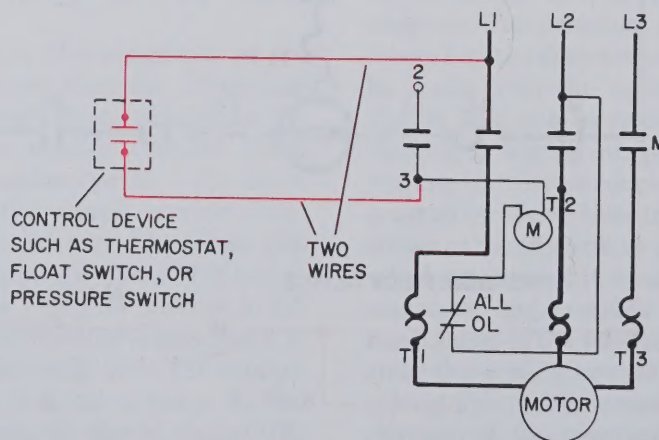


FIG. 5-4 Two wires lead from the pilot device to the starter. The phrases “no-voltage release” and “two wire control” should indicate to you that an automatic pilot device, such as a limit switch or float switch, opens and closes the control circuit through a single contact.

button is pressed, coil M is energized across L1 and L2. This closes contact M to place a shunt circuit around 2-3, the start button. A parallel circuit is formed, with one circuit through push-button contacts 2-3 and one circuit through contact M. As a result, current will flow through the M coil. If pressure is removed from the start button, contacts 2-3 open. The other circuit

through contact M will remain closed, supplying current to coil M and maintaining a starter closed position. Such a circuit is called a maintaining circuit, a sealing circuit, or a holding circuit.

No-Voltage Protection

Three-wire control providing no-voltage protection or low-voltage protection is also a basic and commonly used control circuit. In this type of circuit, three wires are used to control the contactor or starter.

Three-wire control of a starter means that the starter will drop out when there is a voltage failure, but will not pick up automatically when voltage returns. The control circuit in figure 5-5 is completed through the stop button and also through a holding contact (2-3) on the starter. When the starter drops out, the holding contact opens and breaks the control circuit until the start button is pressed to restart the motor.

The main distinction between the two types of control is that in no-voltage release (two-wire control), the coil circuit is maintained through the pilot switch contacts; in no-voltage protection (three-wire control), the circuit is maintained through a stop contact on the push-button station and an auxiliary (maintaining) contact on the starter. The designations "two wire" and "three wire" are used only because they describe the simplest applications of the two types of control. Actually, for more complicated circuits, there may be more wires leading from the pilot device to the starter. However, the principle of two-wire or three-wire control will still apply in these situations.

Three-wire control prevents the restarting of machinery when power is restored. In other words, an operator must press the start buttons to resume production when it is safe to do so.

In figure 5-3(b) contact 2-3 was not included in the two-wire circuit. This contact is the holding or maintaining contact which is connected in a three-wire control circuit as shown in figure 5-5. It is sometimes shown smaller than power contacts.

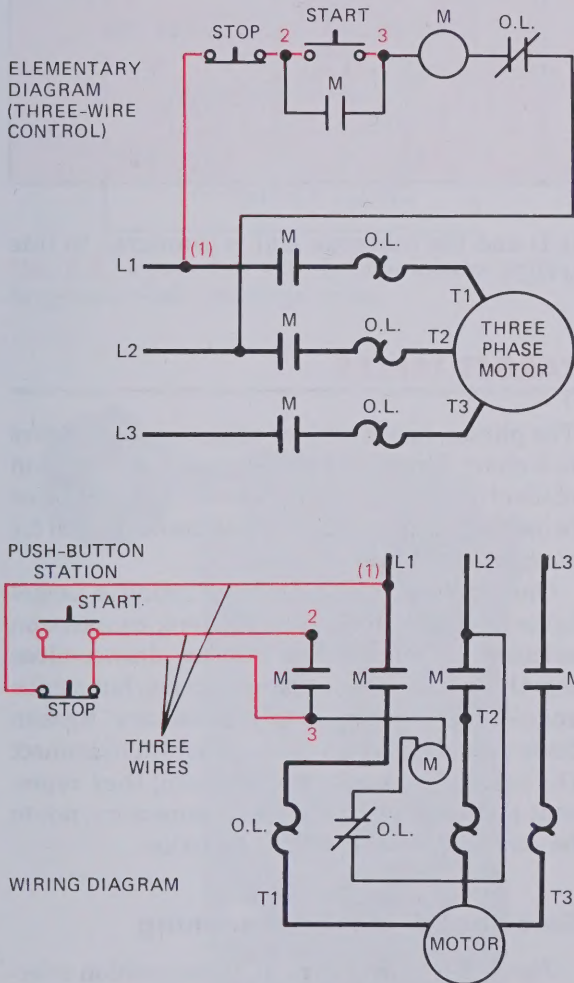


FIG. 5-5 Three wires lead from the pilot device to the starter. The phrases "no-voltage protection" and "three-wire control" should indicate to the electrician that the most common means of providing this type of control is a start-stop push-button station.

TABLE 5-1 Control and Power Connections — 600 Volts or Less — Across-the-Line Starters

	1 PHASE	3 PHASE	DIRECT CURRENT
Line Markings	L1, L2	L1, L2, L3	L1, L2
Ground When Used	L1 Always Ungrounded	L2	L1 Always Ungrounded
O/L Relay Heaters in	L1	T1, T2, T3	L1
Control Circuit Connected to	L1	L1	L1
Control Circuit Switching Connected to	L1, L2	L1, L2	L1, L2
Contactor Coil Connected to	L2	L2	L2
For Reversing Interchange Lines	—	L1, L3	—
Overload Relay Contacts in	L2	L2	L2

Reviewing figure 5-5, it can be seen that when the start button is pressed, coil M is energized from line 1 (L1) through the normally closed stop push button, the depressed start button, the coil, and the overload control contacts to line 2 (L2). When coil M is energized, it closes all M contacts. The maintaining contact (2-3) holds the coil circuit when the start button is released. When the stop push button is pressed, the stop contact opens and the coil is de-energized. As a result, all M contacts are opened and the motor stops. In the event of a motor overload, excessive current is drawn from the line, causing the thermal heaters to overheat. When this happens, the normally closed overload relay control contacts are opened and the motor stops.

CONTROL AND POWER CONNECTIONS

The correct connections and component locations for line and wiring diagrams are indicated in Table 5-1. Compare the information given in the table with actual line diagrams to develop an ability to interpret the table quickly and use it correctly. For example, refer to figure 5-5 and the three-phase column of Table 5-1. Note that the control circuit switching is connected to line 1

(L1) and the contactor coil is connected to line 2 (L2).

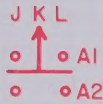
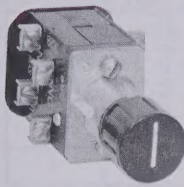
TARGET TABLES

The phrase, *target table* or *sequence chart*, refers to a chart which lists the sequence of operation of identified contacts in a circuit. A target table is useful in interpreting circuit drawings and for simplifying troubleshooting.

One particular advantage of using a target table is shown in figure 5-6. Here, contacts on selector switches need not be drawn close together on the elementary diagram, but can be spaced over the diagram, if necessary. Broken lines should be drawn on the diagram to connect the various contacts of one switch; they represent an insulated mechanical connection, not to be confused with a wire connection.

Selector Switch Diagramming

Figure 5-6 shows a typical, three-position selector switch (left), its line diagram symbol (right), and a target table (bottom) indicating the condition of each contact for each position of the selector switch. The 1 (one) represents closed contacts. A small target table, such as that for



3 POSITION			
	J	K	L
A1	I		
A2			I

I = CONTACT CLOSED

FIG. 5-6 Heavy duty three-position selector switch, diagram symbol, and target table

a single two-circuit, double-contact switch, can be shown above the switch contact on the elementary diagram. Larger target tables should be shown to one side or below the line diagram.

The target table for the three-position selector switch shows that in the OFF position (arrow) no contacts are closed. In the J position, contact A1 is closed and A2 is open. In the L position, A2 is closed and A1 is open.

Drum Switch Diagramming

A drum switch consists of a set of moving contacts mounted on and insulated from a rotating shaft. The switch also has a set of stationary contacts that make and break contact with the moving contacts as the shaft is rotated, figure 5-7. In the single-phase, sample connection diagram, one motor rotation is shown with solid

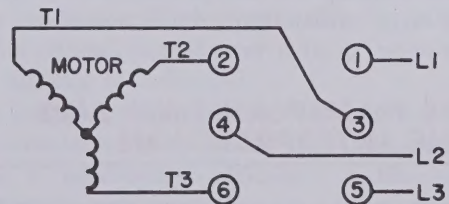
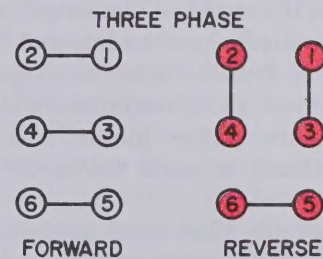
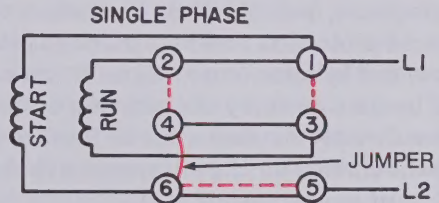
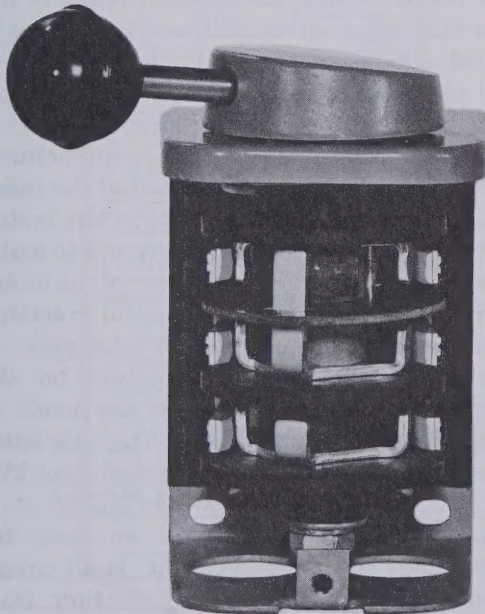
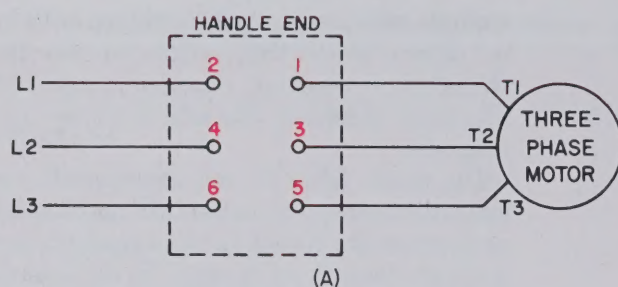


FIG. 5-7 Drum switch with cover removed; diagrams show switch connections to single-phase and three phase motors.



Contact	Forward	Off	Reverse
1-2	I		
3-4	I		
5-6	I		I
1-4			I
2-3			I

(B) "I" = closed contact

FIG. 5-8 A target table is used to assist in the interpretation of drum switch operation where a three-phase or a single-phase motor is reversed by interchanging two motor leads

lines. The other direction is shown with broken lines, reversing one motor winding in relation to the other. A jumper should be added when this switch is used for single phase. The jumper is installed between 4 and 6.

The term *drum switch* is applied to cam switches as well. Drum switches provide a means for starting, stopping, and reversing ac single-phase, polyphase or dc motors without overload protection, or where overload protection is provided by some other means. Drum switches may be used to carry the starting current of a motor directly or they may be used to handle only the current for the pilot devices that control the main motor current.

In figure 5-8, the terminal markings (boxed by broken lines) indicate how the line and load are connected to the drum switch. The target table on the right shows which contacts are closed to reverse the three-phase motor and which contacts are closed to cause the motor to run forward.

Target tables are often used in complicated circuits to simplify the interpretation of the operation of large multicircuit drum switches.

MOTOR NAMEPLATE DATA AND WIRING INTERPRETATION

Figure 5-9 shows a typical motor nameplate for a standard three-phase, nine-lead motor. Table 5-2 shows the letter designations from one

manufacturer for various types of motors. In general, each manufacturer has an individual set of letter designations. For example, a type ML motor may be specified for a particular application. According to data in Table 5-2, a type ML motor has normal starting torque, normal starting current, and normal slip. A mechanical characteristic is that the motor is dripproof.

The nameplate shown in figure 5-9 gives the motor frame number (204) which refers to the frame dimensions given on the manufacturer's detailed dimension sheets. Each motor has a serial or identification number which is also shown on the nameplate. This number is recorded and kept on file by the manufacturer. The record card also includes most of the information shown on the nameplate of the motor. The manufacturer uses the record card to assist in customer service. The purchaser of the motor will find a similar record card helpful in setting up and keeping to maintenance schedules.

The horsepower (hp) rating given on the nameplate refers to the output of the motor, as measured by mechanical means. The code letter on the nameplate indicates the locked rotor kVA input per horsepower as shown in NEMA standards. This code letter shall be used for determining the branch-circuit short-circuit protection and ground-fault protection from applicable tables in the *National Electrical Code*®.

Continuing with figure 5-9, observe the duty cycle for which the motor is designed such as 15 minutes, 30 minutes, or continuous operation.

The *degrees Celsius* rise above ambient temperature for a motor operating under full load is shown in the box under °C rise. R.P.M. on the nameplate refers to the synchronous speed of the motor in revolutions per minute. The current in amperes drawn by the motor is listed under

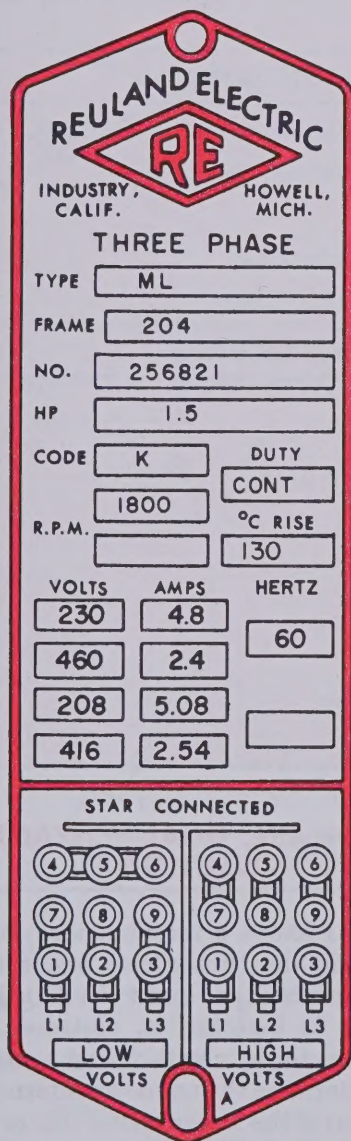


FIG. 5-9 Standard three-phase motor nameplate, nine leads

AMPS and varies according to the voltage system to which the motor is connected. Motors draw half as much current on high voltages as they do on low voltages. However, the same amount of power is used for either high- or low-voltage connections ($P = E \times I$). Low-current connections mean that smaller wire sizes, conduits, feeders, and switch gear can be used. If available, connection to high voltages will mean a financial savings in wiring materials and less wasted electrical energy due to decreased voltage drop in the circuits. The motor starter coil voltage must be equal to the supply voltage (except for separate control, Unit 17), and the overload heaters must be rated for the proper current value.

At the bottom of the nameplate, figure 5-9, the **LOW** volts indication refers to motor terminal connections to 230 and 208 volts; the **HIGH** volts indication refers to 460- and 416-volt connections. For a high-voltage connection, the nameplate shows that motor lead terminals 4 and 7 are connected together, as are 5 and 8, and 6 and 9. The connections are insulated from each other in the motor terminal connection box. The three remaining leads (1, 2, and 3) are connected to three-phase supply lines L1, L2, and L3. Actually, this connection is to the load side of the starter terminals (T1, T2, and T3).

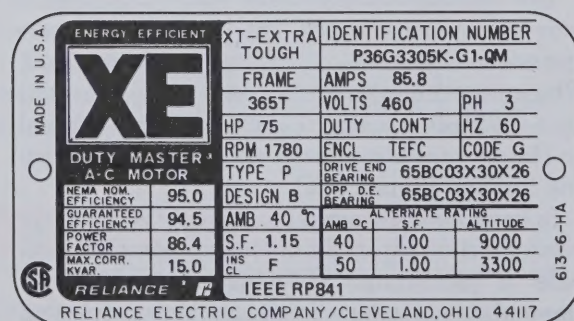
The designation **A** at the bottom of the nameplate in figure 5-9 is part of the manufacturer's information shown in the column headed **NAMEPLATE** in Table 5-2.

The nameplates for some motors include a service factor reference. The service factor of a general-purpose motor is an allowable overload. The amount of allowable overload is indicated by a multiplier. When this multiplier is applied to the normal horsepower rating, the permissible loading is indicated.

In keeping with a greater awareness of energy conservation, many motor manufacturers indicate a percentage efficiency value on the nameplates of selected motors. The nameplate shown in figure 5-10 contains both an efficiency rating (94.1%) and a service factor value (1.15).

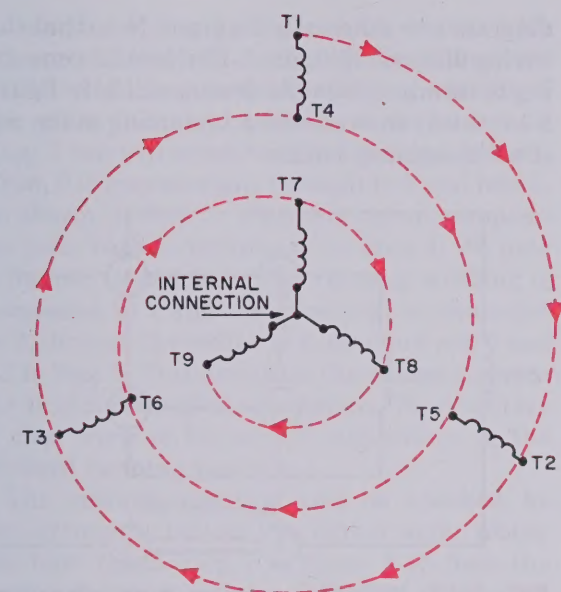
TABLE 5-2 Sample Nameplates and Connection Diagrams

NAMEPLATE	DESCRIPTION	CONNECTION
A	Dual Voltage	Three-phase — Star or Wye
N	Dual Voltage	Three-phase — Delta
F	Dual Voltage	Single-phase
TYPE DESIGNATIONS		
TYPE	ELECTRICAL CHARACTERISTICS	
ML	Normal starting torque and normal starting current. Normal slip.	
HML	High starting torque — low starting current. Normal slip.	
WML	Wound rotor — slip ring.	
MLS	Capacitor start — induction run — single-phase.	
RLS	Repulsion-induction start and run — single-phase.	
MECHANICAL CHARACTERISTICS		
ML	Dripproof	
MLU	Splashproof	
MLE	Totally enclosed nonventilated	
MLF	Totally enclosed fan cooled	
MLV	Vertical solid shaft	
MLVH	Vertical hollow shaft	
GML	Helical Parallel Shaft Motor Reducer	
GMLW	Right Angle Worm Gear Motor Reducer	
Fluid	Fluid Shaft Motors	

**FIG. 5-10** Nameplate for an energy efficient motor (Courtesy Reliance Electric Company)

THREE-PHASE, DUAL-VOLTAGE MOTOR CONNECTIONS

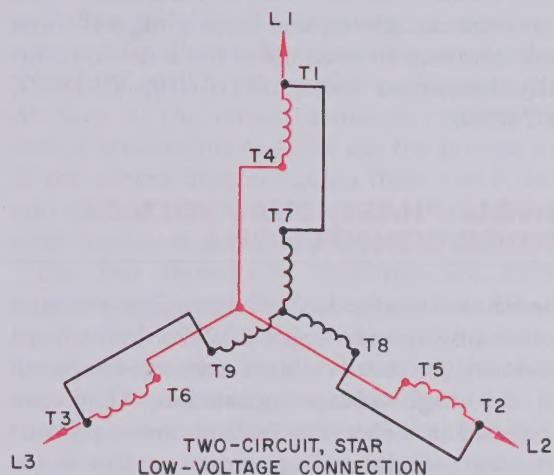
Figure 5-11 shows a recommended method of determining the three-phase motor terminal connections in the event that the motor nameplate is inaccessible, destroyed, or lost when the motor is installed. Test equipment is used to determine the unknown internal wiring connections of the motor, either star or delta. A continuity test will find one group of three common leads. For example, such a test will establish the center of the star high-voltage



STAR HIGH-VOLTAGE CONNECTION

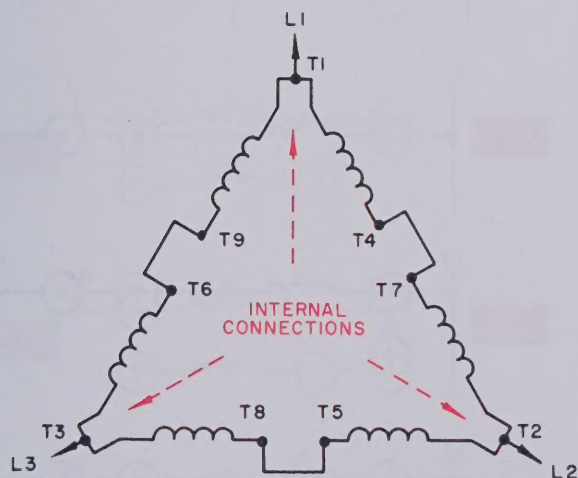
CONNECT

T1 TO L1	T4 TO T7
T2 TO L2	T5 TO T8
T3 TO L3	T6 TO T9



CONNECT T1 TO L1
T2 TO L2
T3 TO L3

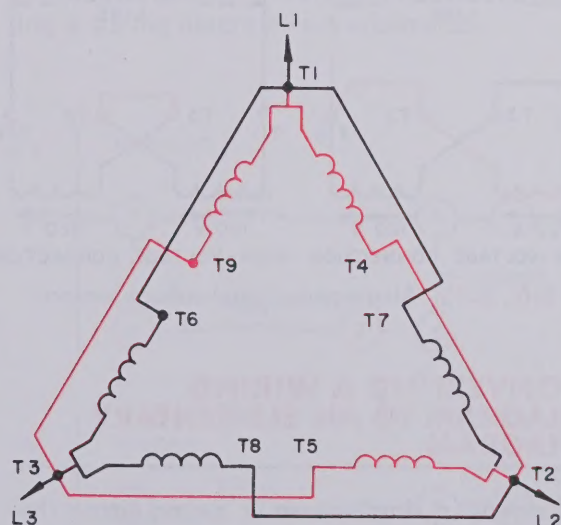
T1 TO T7	T2 TO T8
T3 TO T9	T4 TO T5 T6



HIGH-VOLTAGE SERIES DELTA CONNECTION

CONNECT

L1 TO T1	T4 TO T7
L2 TO T2	T5 TO T8
L3 TO T3	T6 TO T9



LOW-VOLTAGE, TWO-CIRCUIT DELTA CONNECTION

CONNECT

T1, T6, T7 TO L1
T2, T4, T8 TO L2
T3, T5, T9 TO L3

FIG. 5-11 Three-phase motor terminal connections

connection (at T7, T8, and T9) in figure 5-11, upper left. There should be only one group of three motor leads common to each other for a star-connected motor, and three groups of three leads common to each other for a delta, internally connected motor, (T1-T4-T9, T2-T5-T7, T3-T6-T8).

SINGLE-PHASE, DUAL-VOLTAGE MOTOR CONNECTIONS

The connections for dual-voltage, single-phase ac motors are shown in figure 5-12. For low-voltage operation, the stator coils are connected in parallel; for high-voltage operation, they are connected in series. The instantaneous current direction is indicated by arrows at the motor coils. In general, starting windings are factory connected to the terminal screws for 120 volts.

All external wiring motor leads are located in the motor terminal connection or conduit box.

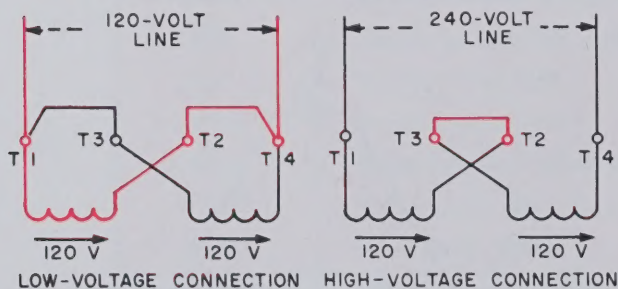


FIG. 5-12 Single-phase, dual-voltage motors

CONVERTING A WIRING DIAGRAM TO AN ELEMENTARY DIAGRAM

To reverse a single-phase ac motor, either the starting or running winding connections (but not both) must be reversed on the line. Note that both connections are not reversed. This action is shown in the wiring diagram of a drum reversing switch, figure 5-13. To show this operation in a simple manner, let's convert the wiring

diagram to a schematic diagram. Note that the wiring diagram in figure 5-13 shows L1 connecting to terminal 1 on the drum switch. In figure 5-14, this is shown in Step 1, starting at the top of an imaginary ladder.

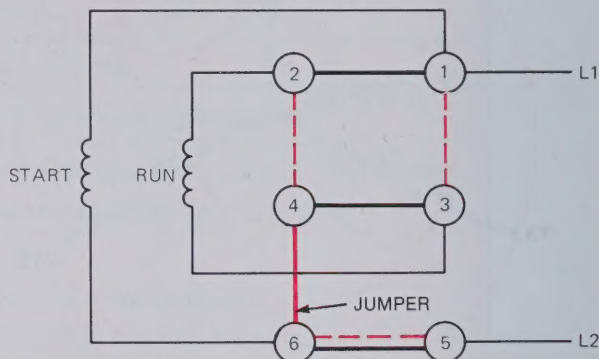


FIG. 5-13 Wiring diagram for a reversing drum switch, controlling a single-phase motor

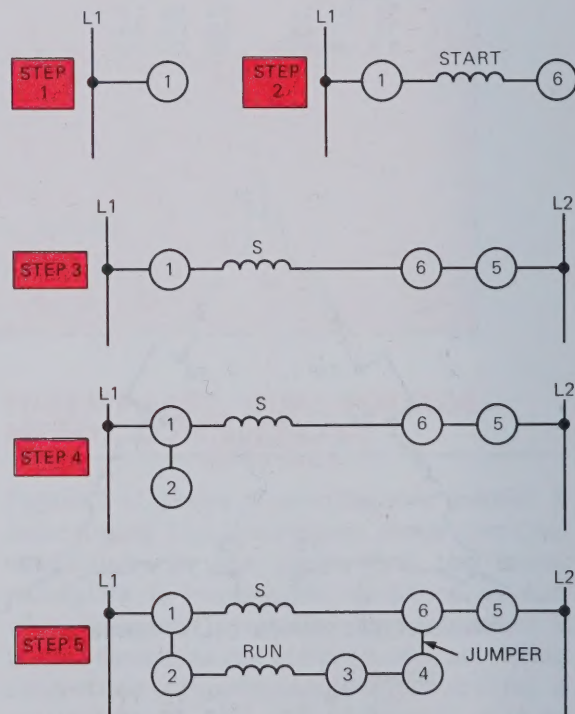


FIG. 5-14 Elementary diagram of solid drum switch lines in figure 5-13, forward position

Referring to Step 1 of figure 5-14, we start with L1 as a vertical line on the left. From terminal 1, the solid line goes to the starting winding of the motor, then to terminal 6, as can be seen in Step 2 (we will come back to terminal 1 later). From 6 it goes straight through to 5 and line 2, as shown in Step 3. With one circuit complete we refer back to terminal 1 in Step 4. We note a jumper from 1 to 2. The running winding is connected to 2 and the other end is connected to 3, through the switch to 4, then to 6 and 5 and L2 in Step 5. This completes the wiring diagram for this portion of the operation. We now have a clear view of the motor connections in the forward running position.

The reverse direction can be checked by converting the broken line circuit to the motor. We have taken Step 1 in figure 5-15 from the wiring diagram in figure 5-13. The start wind-

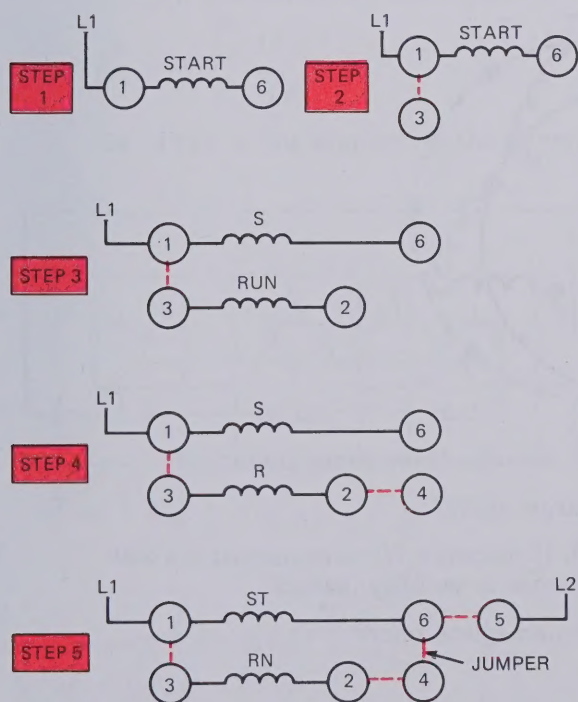


FIG. 5-15 Elementary diagram of broken drum switch lines in figure 5-13, reverse position

ing is connected to numbers 1 and 6 (as in figure 5-14, Step 2). Using another approach this time, we will follow a parallel circuit from number 1 to 3, Step 2. In Step 3, the running winding is reversed, or flipped, by connecting to terminal 3 first, followed by terminal 2 on the right side. At Step 4, the circuit connects through the switch broken line to 4. We see the broken line in the wiring diagram going from 4 to 6, to 5, and then to line 2. This sequence is shown in simplified form going from Step 5 of figure 5-15.

The two elementary drawings are shown together in figure 5-16 for comparison and study. In this form it is clear that the second position, as shown by the broken lines on the drum switch, has reversed connections 2 and 3 on the running winding, with respect to the start winding. On more complicated wiring diagrams, the lines can be traced using different colors to eliminate the possibility of omitting lines. Another method of keeping track of the circuits is to make notes on a scratch pad. When many wires leave a terminal, some method is required to account for them to ensure accuracy in converting a wiring diagram to a schematic.

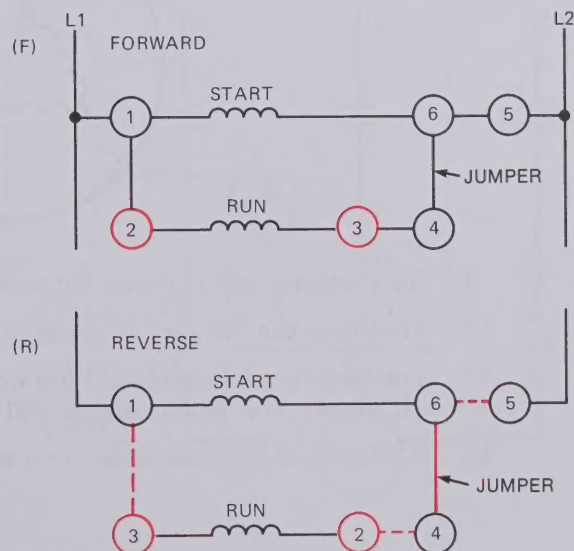
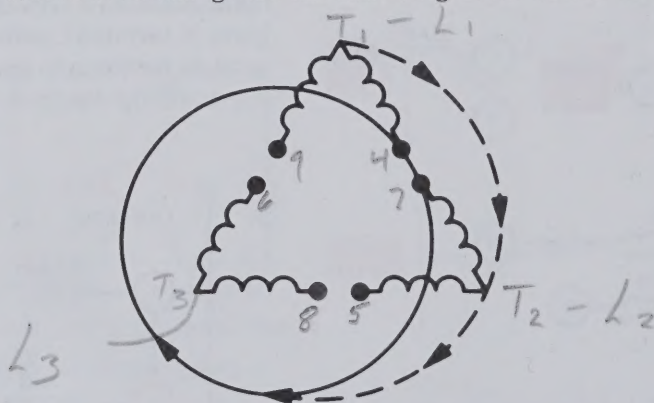


FIG. 5-16 Elementary diagram of figure 5-13

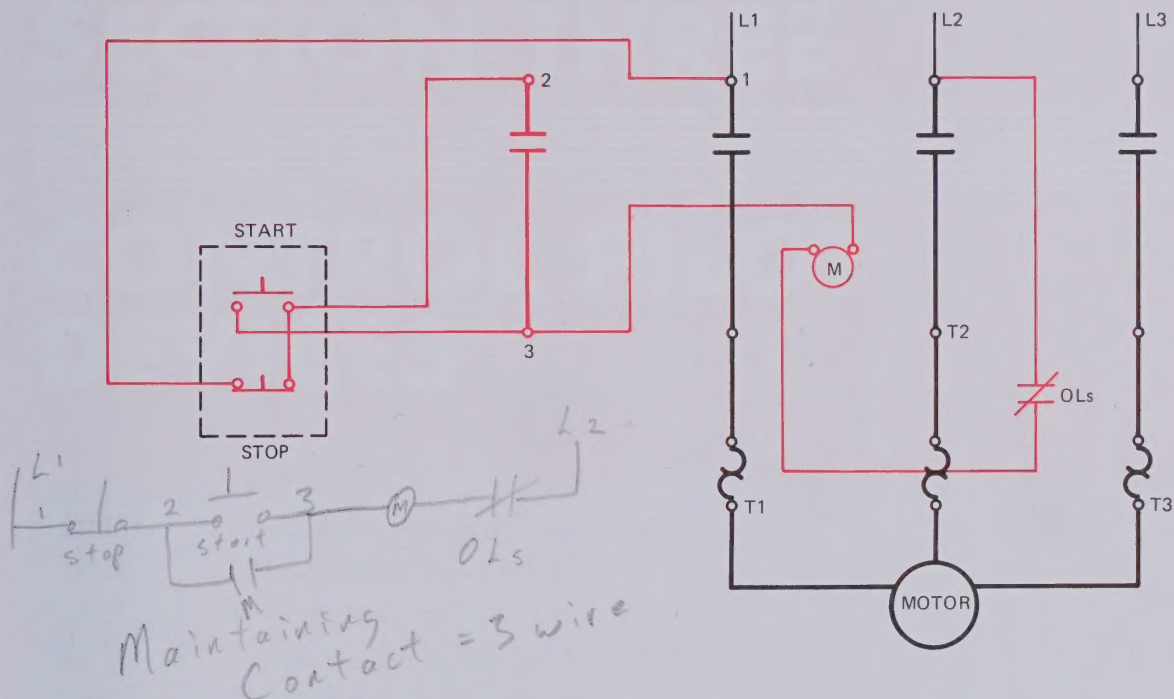
STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. In which diagram do the physical locations of the wiring and the devices match the drawing?
2. Which diagram conveys as much information as possible with the least amount of confusion? *Line - Schematic*
3. Why is it not necessary to show the armature and crossbar or the overload reset mechanism in a wiring diagram? *ALL Electrical*
4. Which control wiring scheme can cause damage to industrial production or processing equipment with the sudden restart of machines upon restoration of the power? *Two Wire*
5. In developing line or wiring diagrams, in which lines should the overload relays be placed for three-phase motor starters? *Feed to Motor all lines*
6. In which line of a three-phase starter are the overload relay contacts connected? *Control Circuit L2*
7. The control circuit is connected to which lines for a three-phase motor starter? *L1 L2*
8. Identify the terminal markings for the following delta-wound motor.

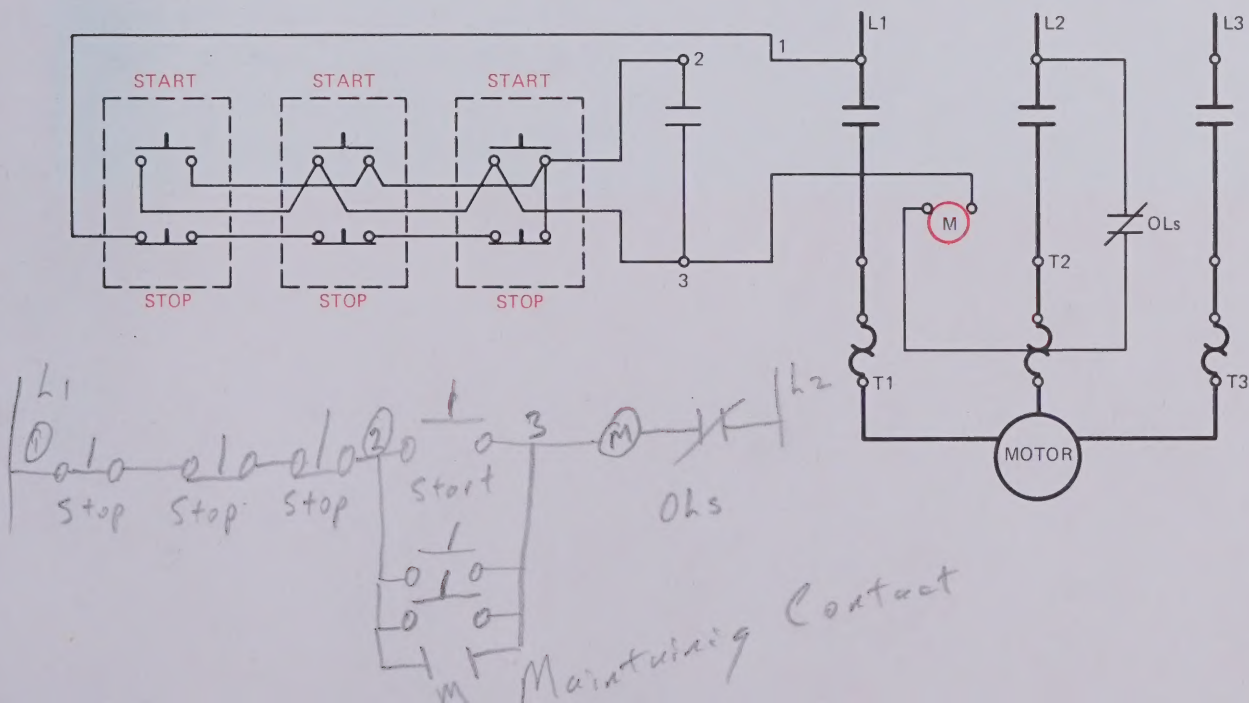


9. The contactor coil is connected to which line of a three-phase contactor? *L2 Directly*
10. What does the "X" or "1" mean on a target table? *Closed Contacts*
11. A motor nameplate reads 230/460 volts, 30-15 amperes. When connected to a 440-volt supply, how much current will the motor draw fully loaded?
12. To what does the code letter on a motor nameplate refer?

13. Draw an elementary line diagram of the control circuit from the following wiring diagram. Exclude power or motor circuit wiring.



14. Draw a line diagram of the following control circuit.



SECTION THREE

CONTROL PILOT DEVICES

- UNIT 6 Push Buttons and Control Stations**
- UNIT 7 Relays and Contactors**
- UNIT 8 Timing Relays**
- UNIT 9 Pressure Switches and Regulators**
- UNIT 10 Float Switches**
- UNIT 11 Flow Switches**
- UNIT 12 Limit Switches and Proximity Control**
- UNIT 13 Phase Failure Relays**
- UNIT 14 Solenoid Valves**
- UNIT 15 Temperature Switches**

UNIT 6 Push Buttons and Control Stations

Objectives After studying this unit, the student will be able to:

- Describe the difference between closed and open push buttons
- Draw the wiring diagram symbols for push buttons and pilot lights
- Draw simple circuits using normally open and closed push buttons
- Connect combination push buttons in simple circuits
- Explain single and double break contacts
- List type of control operators on control stations
- Draw simple circuits using a selector switch
- Wire simple circuits with a selector switch

PUSH BUTTONS

A push-button station is a device that provides control of a motor through a motor starter by pressing a button which opens or closes contacts. It is possible to control a motor from as many places as there are stations — through the same magnetic controller. This can be done by using more than one push-button station. A single circuit push-button station is shown in figure 6-1.

Two sets of momentary contacts are usually provided with push buttons so that when the button is pressed, one set of contacts is opened and the other set is closed. The use of this combination push button is simply illustrated in the wiring diagram of figure 6-2. When the push button is in its normal position as shown in figure 6-2(A), current flows from L1 through the

normally closed contacts, through the red pilot light (on top) to L2 to form a complete circuit; this lights the lamp. Since the power push-button circuit is open by the normally open contact, the green pilot lamp does not glow. Note that this situation is reversed when the button is pushed, see figure 6-2(B). Current now flows from L1 through the pushed closed contact and lights the green pilot lamp when completing the circuit to L2. The red lamp is now out of the circuit and does not glow. However, because the push buttons are momentary contact (spring loaded), we return to the position shown in figure 6-2(A) when pressure on the button is released. Thus, by connecting to the proper set of contacts, either a normally open or a normally closed situation is obtained. *Normally open* and *normally closed* mean that the contacts are in a rest position, held there by spring tension, and are not subject

to either mechanical or electrical external forces. (See the glossary in the Appendix for more detailed definitions.)

Push-button stations are made for two types of service: *standard duty* stations for normal



FIG. 6-1 Push-button control station with general purpose enclosure, usually made of molded plastic or sheet metal. Corresponding wire diagram symbols are shown for single-circuit push buttons. (Courtesy Square D Co.)

SINGLE CIRCUIT	
NO	NC

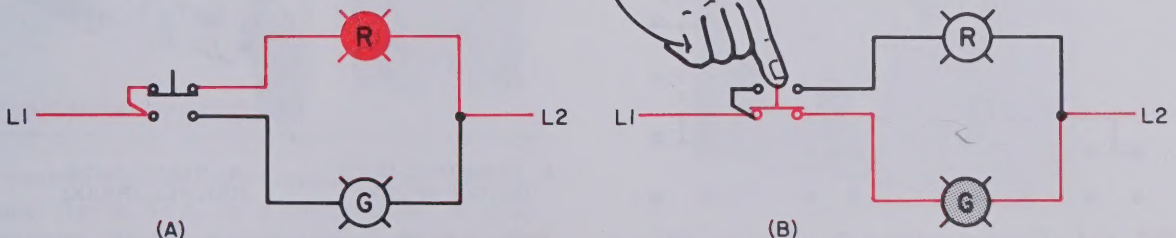


FIG. 6-2 Combination push button: (A) Red pilot light is lit through normally closed push-button contact (B) Green pilot light is lit when the momentary contact button is pushed.

applications safely passing coil currents of motor starters up to size 4, and *heavy duty* stations, when the push buttons are to be used frequently and subjected to hard or rough usage. Heavy duty push-button stations have higher contact ratings.

The push-button station enclosure containing the contacts is usually made of molded plastic or sheet metal. Some double-break contacts are made of copper. However, in most push buttons, silver-to-silver contact surfaces are provided for better electrical conductivity and longer life.

Figure 6-3 shows a combination, normally open and normally closed, push-button unit with a mushroom head for fast and easy access such as may be required in a safety circuit. This is also called a *palm-operated push button*, especially when it is used as a safety device for both operator and machine, such as a punch-press or emergency stop in a control station. The push-button terminals in figure 6-2 represent one-half of the terminals shown in figures 6-3 and 6-4, for a double-pole, double-throw push button.

Since control push buttons are subject to high momentary voltages caused by the inductive effect of the coils to which they are connected,

good clearance between the contacts and insulation to ground and operator is provided.

The push-button station may be mounted adjacent to the controller or at a distance from it. The amount of current broken by a push button is usually small. As a result, operation of the controller is hardly affected by the length of the wires leading from the controller to a remote push-button station.

Push buttons can be used to control any or all of the many operating conditions of a motor, such as *start*, *stop*, *forward*, *reverse*, *fast*, and *slow*. Push buttons also may be used as remote stop buttons with manual controllers equipped with potential trip or low-voltage protection.

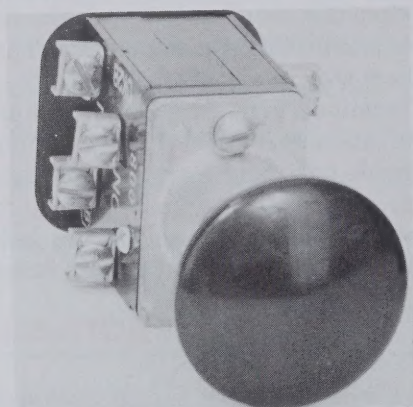


FIG. 6-3 Open push-button unit with mushroom head (Courtesy Allen-Bradley Co.)

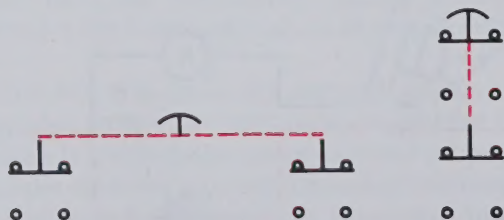


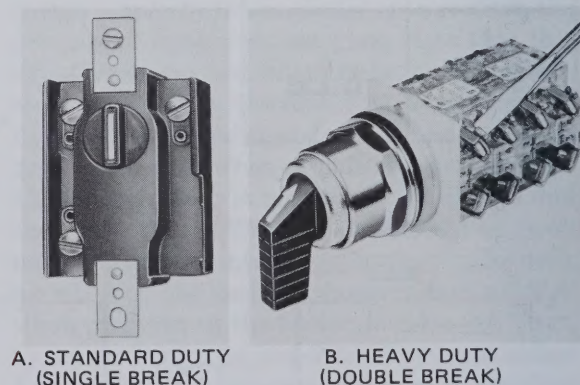
FIG. 6-4 Terminal configurations used by different manufacturers, of figure 6-3 push button. Both configurations represent the same push button.

SELECTOR SWITCHES

Selector switches, as can be seen in figure 6-5, are usually “maintained” contact position, with three and sometimes two selector positions. Selector switch positions are made by turning the operator knob—not pushing it. Figure 6-5(A) is a single-break contact arrangement, figure 6-5(B) is a double-break contact, disconnecting the control circuit at two points. These switches may also have a spring return to give momentary contact operation.

Figure 6-6(A) shows a single break contact selector switch connected to two lights. The red light may be selected to glow by *turning* the switch to the red position, figure 6-6(B). Current now flows from line 1 through the selected red position of the switch, through the red lamp to line 2, completing the circuit. Note this switch has an *off* position in the center. There are two position selector switches available, with no *off* position. Here, whichever light is selected would burn continuously.

Figure 6-7(A) is an elementary diagram of the heavy duty, double-break selector switch similarly shown in figure 6-5. Note that the red light will glow (see A) with the two-position switch in this position, the green indicating lamp is de-



A. STANDARD DUTY (SINGLE BREAK)

B. HEAVY DUTY (DOUBLE BREAK)

FIG. 6-5 Open selector switches: A. (Courtesy EATON Corp. Cutler-Hammer Products) B. (Courtesy Square D Co.)

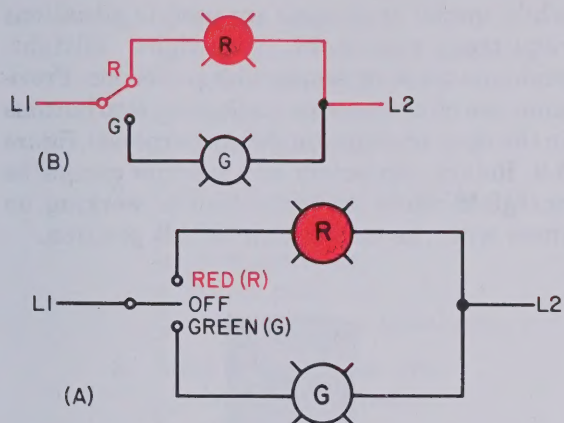


FIG. 6-6 Elementary diagram using (A) A single-break, three-position selector switch and (B) Two-position, single-break switch

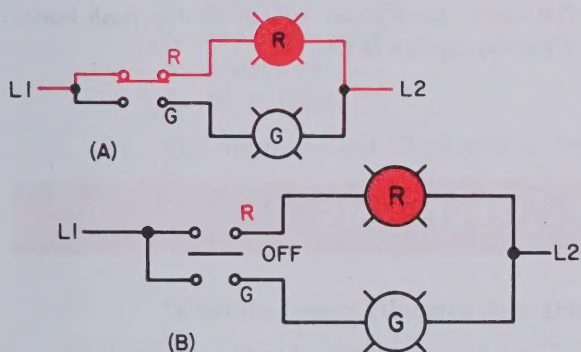


FIG. 6-7 Heavy-duty, double-break selector switch for (A) Two position and (B) Three position switches

energized, there is no “off” position. Figure 6-7(B) illustrates a three-position selector switch containing an “off” position. Both lamps may be turned off using this switch, but not in (A).

CONTROL STATIONS

A control station may contain push buttons alone, figure 6-8A, or a combination of push buttons, selector switches and pilot lights (indicating lights), figure 6-8B. Indicating lights may be mounted in the enclosure. These lights

are usually red or green and are used for communication and safety purposes. Other common colors available are amber, blue, white, and clear. They indicate when the line is energized, the motor is running, or any other condition is designated.

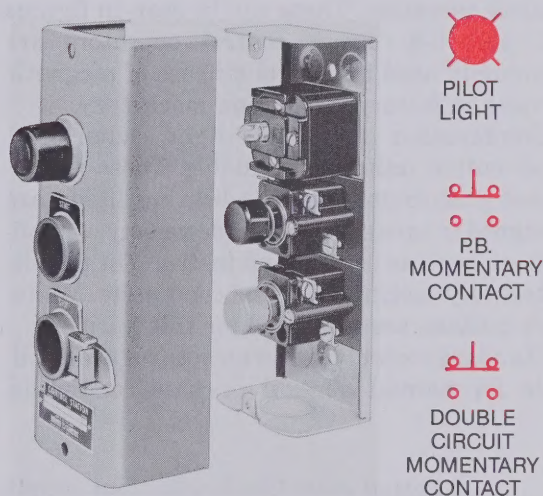


FIG. 6-8(A) Push-button control station with pilot light and associated wiring symbols for components. (Courtesy Square D Co.)

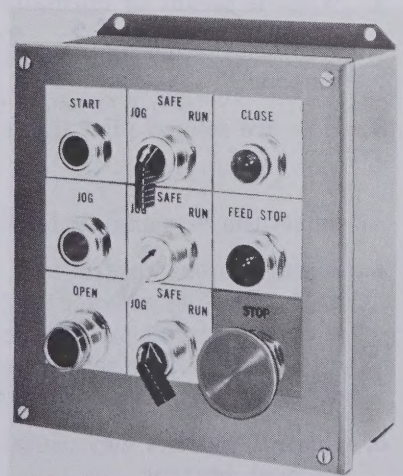


FIG. 6-8(B) Control station with push buttons, selector switches, and indicating lights Courtesy Square D Co.)

Control stations may also include switches that are key, coin, or hand operated wobble sticks. A wobble stick is a stem-operated push button, for operation from any direction. There are ball lever push button operators for a gloved hand or for frequent operations.

Nameplates are installed to designate each control operation. These can be seen in figures 6-1 and 6-8. These control operators are commonly used in control circuits of magnetic devices in factory production machinery.

Combination indicating light, nameplate, push-button units are available. These illuminated push buttons and indicating lights are designed to save space in a wide variety of applications such as control and instrument panels, laboratory instruments, and computers. Miniature buttons are also used for this purpose.

Standard control station enclosures are available for normal general purpose conditions,

while special enclosures are used in situations requiring watertight, dust-tight, oiltight, explosion-proof, or submersible protection. Provisions are often made for *padlocking* stop buttons in the open position (for safety purposes), figure 6-9. Relays, contactors and starters cannot be energized while an electrician is working on them with the stop button in this position.



FIG. 6-9 Mechanical lockout-on-stop push button (Courtesy Square D Co.)

STUDY ■ DISCUSSION ■ TEST QUESTIONS

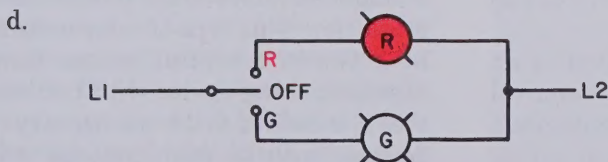
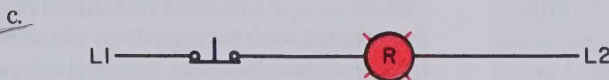
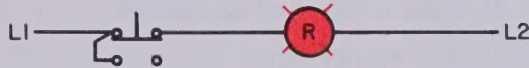
1. What is meant by normally open contacts and normally closed contacts?
2. Why is it that normally open and normally closed contacts cannot be closed simultaneously? *Contacts are in rest position*
3. How are colored pilot lights indicated in wiring diagrams? *Mechanical Interlocks*

Circle with a letter inside

Select the *best* answer for each of the following.

4. A single-break control is a
 - a. heavy duty selector switch
 - b. single-circuit push button
 - c. standard duty selector switch
 - d. double-circuit push button
5. Control stations may contain
 - a. push buttons
 - b. selector switches
 - c. indicating lights
 - d. all of these

6. A wobble stick is
- a. operated from any direction
 - b. knob controlled
 - c. palm controlled
 - d. glove operated
7. Common selector switches are
- a. one position
 - b. two positions
 - c. three positions
 - d. two and three positions
8. Most push buttons are
- a. momentary contact
 - b. single contact
 - c. double contact
 - d. a combination
9. Control station enclosures are
- a. general purpose
 - b. explosion proof
 - c. watertight
 - d. all of these
10. The diagram that illustrates a single circuit, normally closed push button is



UNIT 7 *Relays and Contactors*

Objectives After studying this unit, the student will be able to:

- Tell how magnetic relays differ from contactors
- List the principal uses of each magnetic relay and contactor
- Describe the operation of magnetic blowout coils and how they provide arc suppression
- Identify single- and double-throw contacts; single- and double-break contacts
- Draw the wiring diagram symbols for contactors and relays
- Describe the operation and use of mechanically held relays
- Draw elementary diagrams of control and load for mechanically held relays and contactors
- Connect wiring for mechanically held relays and contactors
- Identify dust-tight, plug-in and solid-state relays

CONTROL RELAYS

Control magnetic relays are used as auxiliary devices to switch control circuits and large motor starter and contactor coils, and to control small loads such as small motors, solenoids, electric heaters, pilot lights, audible signal devices and other relays, figure 7-1.

A magnetically held relay is operated by an electromagnet which opens or closes electrical contacts when the electromagnet is energized. The position of the contacts changes by spring and gravity action when the electromagnet is de-energized.

Relays are generally used to enlarge or amplify the contact capability, or multiply the switching

functions of a pilot device by adding more contacts to the circuit, figure 7-2.

Most relays are used in control circuits; therefore, their lower ratings (0-15 amperes maximum to 600 volts) show the reduced current levels at which they operate.

Magnetic relays do not provide motor overload protection. This type of relay ordinarily is used in a two-wire control system (any electrical contact-making device with two wires). Whenever it is desired to use momentary contact pilot devices, such as push buttons, any available normally open contact can be wired as a holding circuit in a three-wire system (see Unit 15 and Glossary in the Appendix). The contact arrangement and a description of the magnetic

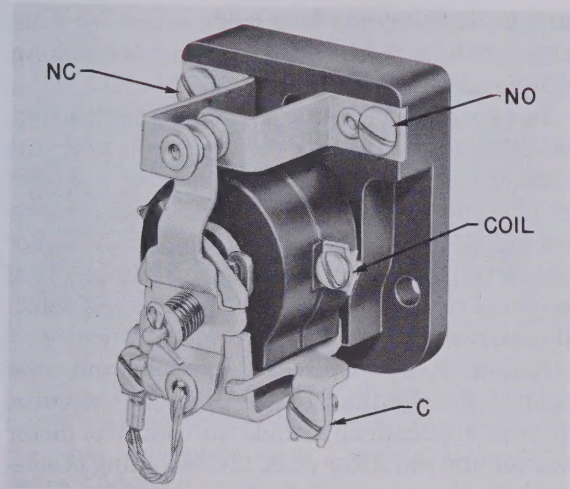


FIG. 7-1 Single-pole, double-throw, single-break ac control relay with wiring symbols (Courtesy Square D Co.)

structure of relays were presented in Unit 3, as motor starters. Starters, contactors, and relays are similar in construction and operation but are not identical.

Control relays are available in single- or double-throw arrangements with various combinations of normally open (NO) and normally closed (NC) contact circuits. While there are some single-break contacts used in industrial relays, most of the relays used in machine tool control have double-break contacts. The comparison can be seen in figures 7-1 and 7-2A. Looking at the relay contacts in figure 7-2A, note the upper contact being open at two points, making it a double break. The lower contact is normally closed with a circuit from the left-hand terminal screw, through the double-break contact to the right-hand terminal screw. One set of normally closed and one normally open contacts represents this description with the wiring symbols. This is also a single-throw contact

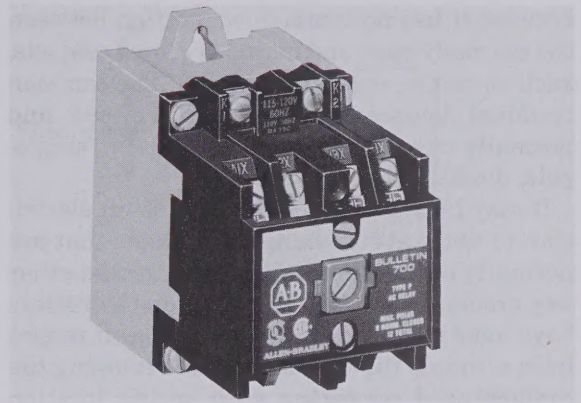


FIG. 7-2(A) Four-pole control relay with four normally open contacts. To change from the normally open to the normally closed reversing contact, invert 180° and reinstall cartridges (Courtesy Allen-Bradley Co.)

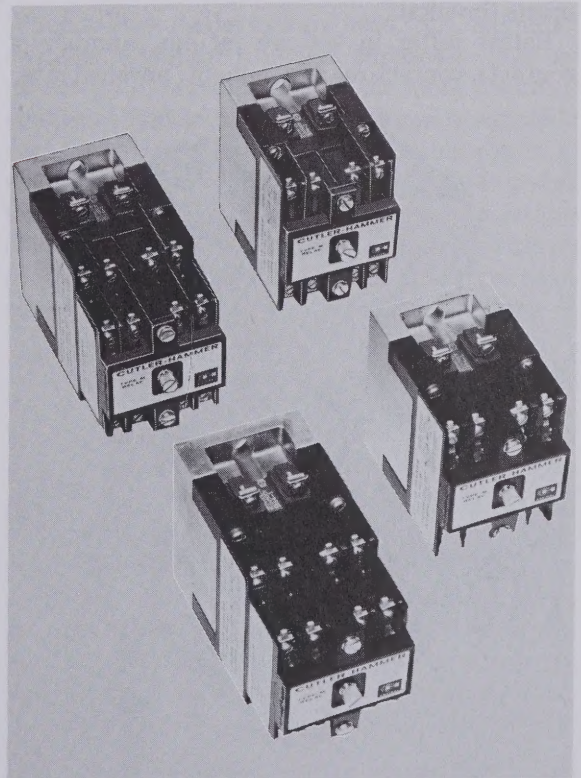


FIG. 7-2(B) Multipole relays (Courtesy EATON Corp., Cutler-Hammer Products)

because it has no common connection between the normally open and normally closed contacts, such as can be seen in figure 7-1. The common terminal between the normally closed and normally open contacts makes this a “single-pole, double-throw” relay.

It may be of particular interest to an electrician to know about changing contacts that are normally open to normally closed, or the other way around, NC to NO. Most machine tool relays have some means to make this change. It ranges from a simple flip-over contact to removing the contacts and relocating with spring location changes.

Also, by overlapping contacts in this case, one contact can be arranged to operate at a different time relative to another contact on the same relay. For example, the normally open contact closes (makes) before the normally closed contact opens (breaks).

Relays differ in voltage ratings, number of contacts, contact rearrangement, physical size,

and in attachments to provide accessory functions such as mechanical latching and timing. (These are discussed later in this unit.)

In using a relay for a particular application, one of the first steps should be to determine the control (coil) voltage at which the relay will operate. The necessary contact rating must be made, as well as the number of contacts and other characteristics needed. Because of the variety of styles of relays available, it is possible to select the correct relay for almost any application.

Relays are used more often to open and close control circuits than to operate power circuits. Typical applications include the control of motor starter and contactor coils, the switching of solenoids, and the control of other relays. A relay is a small but vital switching component of many complex control systems. Low-voltage relay systems are used extensively in switching residential and commercial lighting circuits and individual lighting fixtures.

While control relays from various manufacturers differ in appearance and construction, they are interchangeable in control wiring systems if their specifications are matched to the requirements of the system.

Control relays are available in many shapes and configurations. Figure 7-3 shows a dustproof, transparent enclosure of a control relay. The terminals plug in, like an electron tube. Another type of relay is the very small reed relay, with the contacts enclosed in glass. It is operated with a magnetic field.

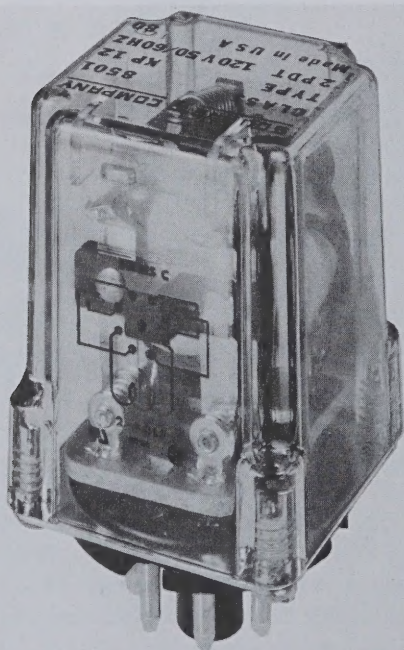


FIG. 7-3 Dustproof, transparent enclosed control relay (Courtesy Square D Co.)

SOLID-STATE RELAY

Figure 7-4 shows one type of solid-state relay. Note the standard electrical control symbols designating the connecting terminals. With the proper voltages, the connections are similar to those of electromagnetic relays. In comparison to an electromagnetic relay, the solid-state relay has no coil or contacts and requires only minimum values of voltage and current to turn it on and off. The solid-state relay depends on elec-

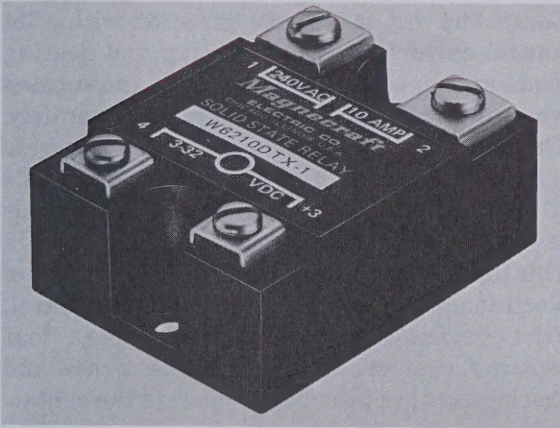


FIG. 7-4 Solid-state relay (Courtesy Magnecraft Electric Company)

tronic devices, such as transistors and silicon controlled rectifiers (SCR) for switching.

THE TRANSISTOR AS A SWITCH

Figure 7-5 shows a basic solid-state switching device used in a logic component (relay). The transistor is the heart of the element. The base of the transistor controls the current flow between the emitter and the collector. In this type of transistor, a negative voltage on the base allows emitter-base current to flow. This is due to the properties of the material at the junction of the emitter and the base. The emitter-base current causes the transistor to conduct a current flow from the emitter to the collector. A positive voltage on the base prevents emitter-base current from flowing, and the transistor stops conducting. Therefore, it behaves as a closed contact in the first state, and as an open contact in the second.

For this reason, the action is called solid-state switching; that is, no moving contacts are required. There is only an electrical signal to open or close the circuit. As a result, the solid-state device is very reliable and has an exceptionally long life. Solid-state devices are not subject to arcing, wear, or deterioration, as are magnetic relays.

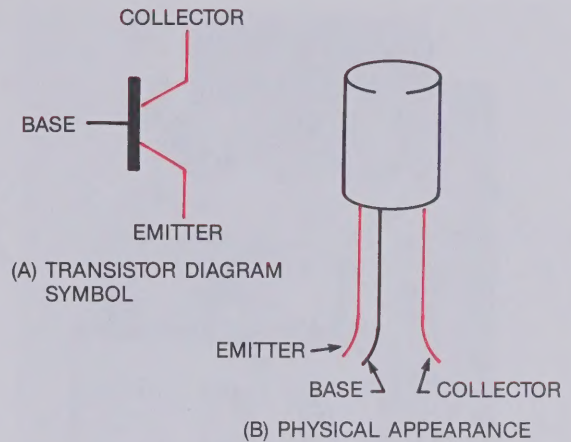


FIG. 7-5 Transistor solid-state switching device

SURGE PROTECTION

When solid-state devices are used with magnetic switches, a voltage transient suppressor may be necessary to prevent some of the more harmful electrical “noise.” Figure 7-6 shows a suppressor of this type. Figure 7-7 illustrates a suppressor installed on a magnetic relay to assist in its accuracy of operation and the protection of solid-state devices. Much more sophisticated protection is required for microcomputers that control robots on assembly production lines.

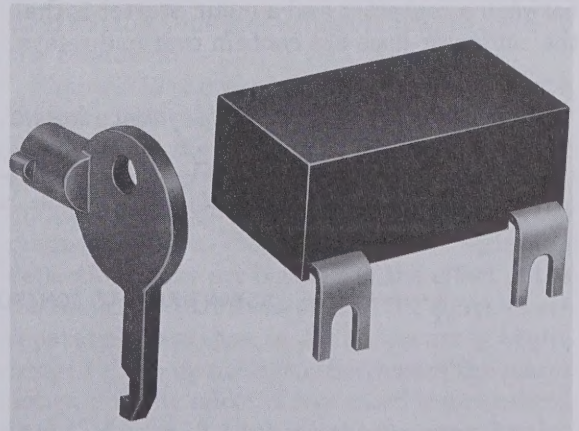


FIG. 7-6 Transient suppressor (Courtesy Square D Co.)

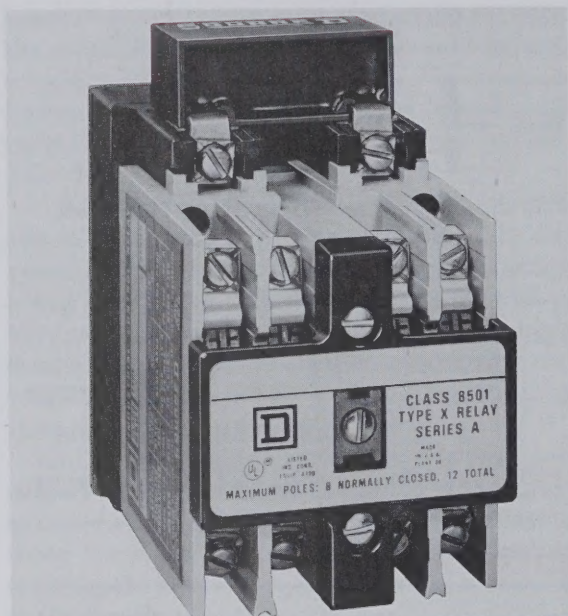


FIG. 7-7 Transient suppressor installed on a magnetic relay (Courtesy Square D Co.)

CONTACTORS

Magnetic contactors are electromagnetically operated switches that provide a safe and convenient means for connecting and interrupting branch circuits. The principal difference between a contactor and a motor starter is that the contactor does not contain overload relays.

Contactors are used in combination with pilot control devices to switch lighting and heating loads and to control ac motors in those cases where overload protection is provided separately. The larger contactor sizes are used to provide remote control of relatively high-current circuits where it is too expensive to run the power leads to the remote controlling location, figure 7-8. This flexibility is one of the main advantages of electromagnetic control over manual control. Pilot devices such as push buttons, float switches, pressure switches, limit switches, and thermostats are provided to operate the contactors.

Magnetic Blowout

The contactors shown in figures 7-9 and 7-10 operate on alternating current. Heavy-duty contact arc-chutes are provided on most of these larger contactors, figure 7-9. The chutes contain heavy copper coils called blowout coils, mounted above the contacts in series with the load to provide better arc suppression. These magnetic blowout coils help to extinguish an electric arc at contacts opening under alternating-current and direct-current loads. These arcs may be similar in intensity as the electric arc welding process. An arc-quenching device is used to assure longer contact life. Since the hot arc is transferred from the contact tips very rapidly, the contacts remain cool and so they last longer.

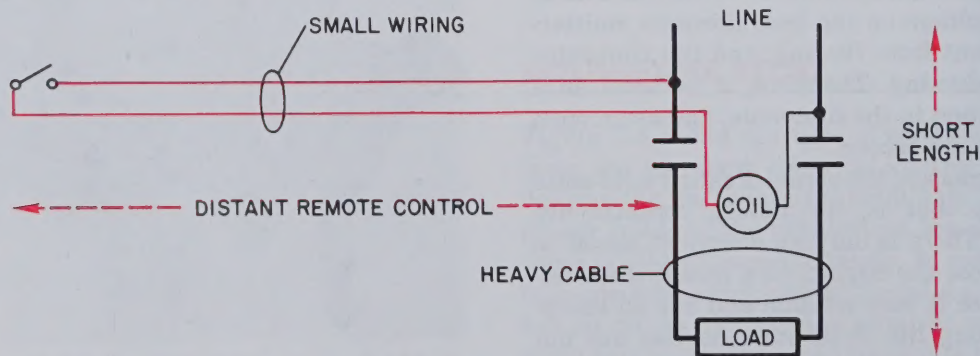


FIG. 7-8 An advantage of a remote control load

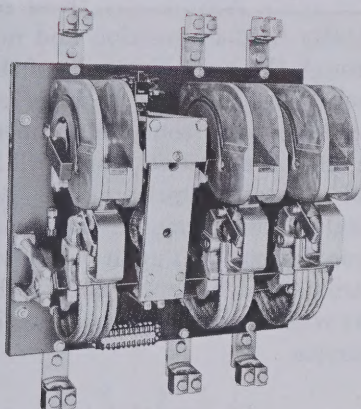


FIG. 7-9 Open magnetic contactor "clapper" action Size 6 (Courtesy Square D Co.)

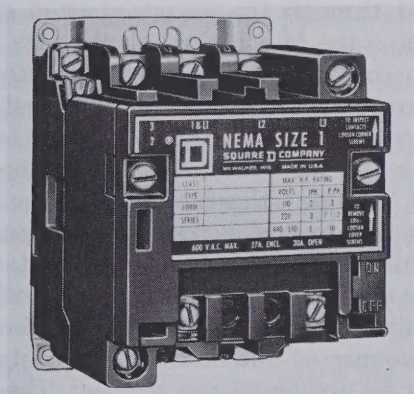


FIG. 7-10 Contactor, Size 1. Contacts are accessible by removing the two front screws. (Courtesy Square D Co.)

Contactors and motor starter contacts that frequently break heavy currents are subject to a destructive burning effect if the arc is not quickly extinguished. The arc that is formed when the contacts open can be lengthened, and extinguished by motor action if it is in a magnetic field. This magnetic field is provided by the magnetic blowout coil. Since the coil of the magnet is usually in series with the line, the field strength and extinguishing action are in proportion to the size of the arc.

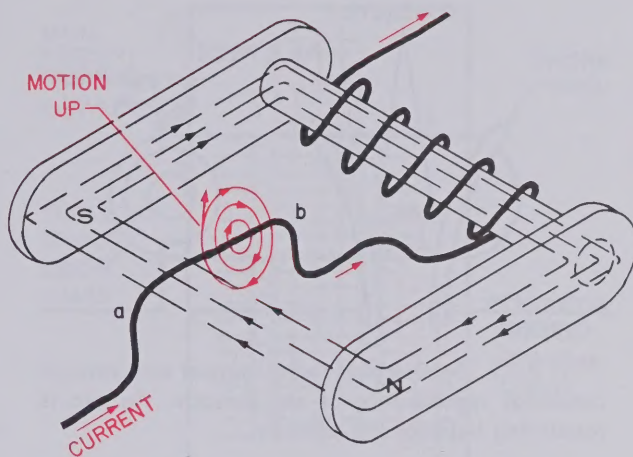


FIG. 7-11 Illustration of the magnetic blowout principle. Straight conductor simulates arc.

Figure 7-11 is a sketch of a blowout magnet with a straight conductor (ab) located in the field and in series with the magnet. This figure can represent either dc polarity or instantaneous ac. With ac current, the blowout coil magnetic field and the conductor (arc) magnetic field will reverse simultaneously. According to Fleming's left-hand rule, motor action will tend to force the conductor in an upward direction. The application of the right-hand rule for a single conductor shows that the magnetic field around the conductor aids the main field on the bottom and opposes it on the top, thus producing an upward force on the conductor.

Figure 7-12 shows a section of figure 7-11 with the wire (ab) replaced by a set of contacts. The contacts have started to open and there is an arc between them.

Figure 7-13 shows what happens because of the magnetic action. Part A shows the beginning deflection of the arc because of the effect of the motor action. Part B shows that the contacts are separated more than in A and the arc is beginning to climb up the horns because of the motor action and the effect of increased temperature. Part C of figure 7-13 shows the arc near the tips of the horns. At this point, the arc is so lengthened that it will be extinguished.

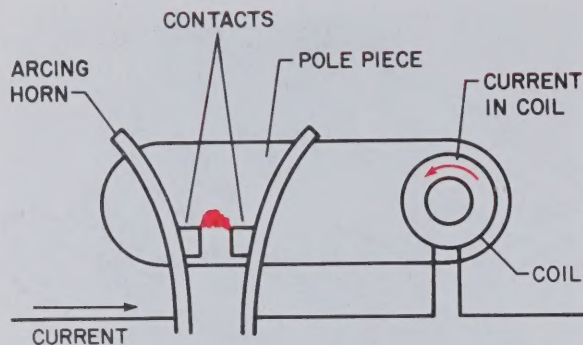


FIG. 7-12 Section of blowout magnet with straight conductor replaced by a set contacts. An arc is conducting between the contacts.

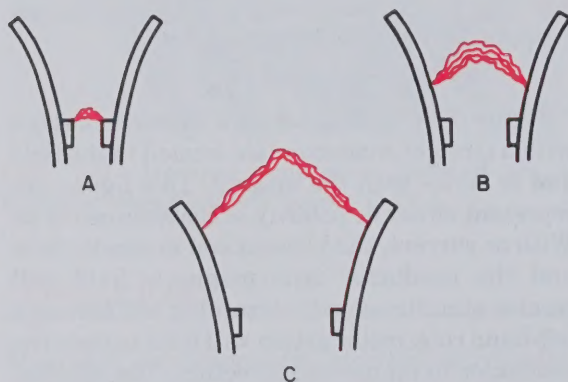


FIG. 7-13 Arc deflection between contacts

The function of the blowout magnet is to move the arc upward at the same time that the contacts are opening. As a result, the arc is lengthened at a faster rate than will normally occur because of the opening of the contacts alone. It is evident that the shorter the time the arc is allowed to exist, the less damage it will do to the contacts. Most arc quenching action is based upon this principle.

AC MECHANICALLY HELD CONTACTORS AND RELAYS

A mechanically held relay, or contactor, is operated by electromagnets but the electromagnets

are automatically disconnected by contacts within the relay. Accordingly, these relays are mechanically held in position and no current flows through the operating coils of these electromagnets after switching. It is apparent, therefore, that near continuous operation of multiple units of substantial size will lower the electrical energy requirements. Also, the magnetically held relay, in comparison, will change contact position upon loss of voltage to the electromagnet, whereas the mechanically held relay will respond only to the action of the control device.

Sequence of Operation

Referring to figure 7-14A, when the “on” push button is pressed momentarily, current flows from L1 through the *on* push-button contact energizing the M coil through the now closed clearing contact, to L2. The relay now closes and latches mechanically. At the same time it closes M contacts (in figure 7-14B), lighting a bank of lamps when the circuit breaker is closed. To unlatch the relay, thereby turning the lamps off, the *off* button is pressed momentarily, unlatching the relay and opening contacts M, turning off the lamps. Most operating coils are not designed for continuous duty. Therefore, they are disconnected automatically by contacts to prevent an accidental coil burnout. These coil clearing contacts change position alternately with a change in contactor latching position.

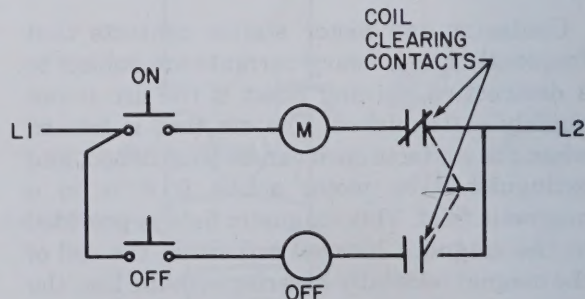


FIG. 7-14(A) Mechanically held relay control circuit

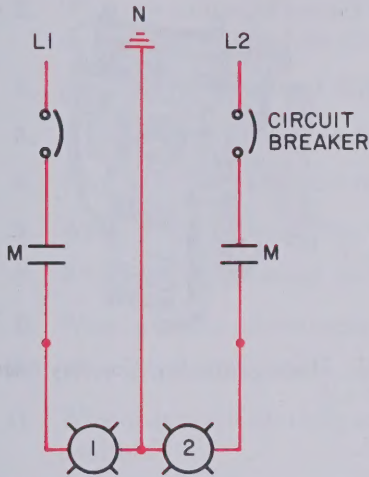


FIG. 7-14(B) Load connections for a 115/230-volt, three-wire load

Figure 7-15 shows a three-phase power load application using one main contactor to disconnect the distribution panel. Selective single, or three-phase, branch circuits may be switched independently by other mechanically held contactors or relays.

These mechanically held contactors and relays are electromechanical devices, figure 7-16. They

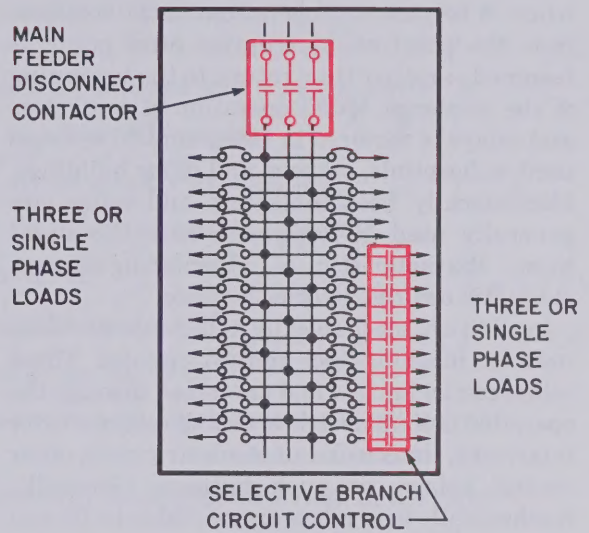


FIG. 7-15 Mechanically held contactor loads for three-phase power

provide a safe and convenient means of switching circuits where *quiet operation*, *energy efficiency*, and *continuity of circuit connection* are requirements of the installation. For example, circuit continuity during power failures is often important in automatic processing equipment,

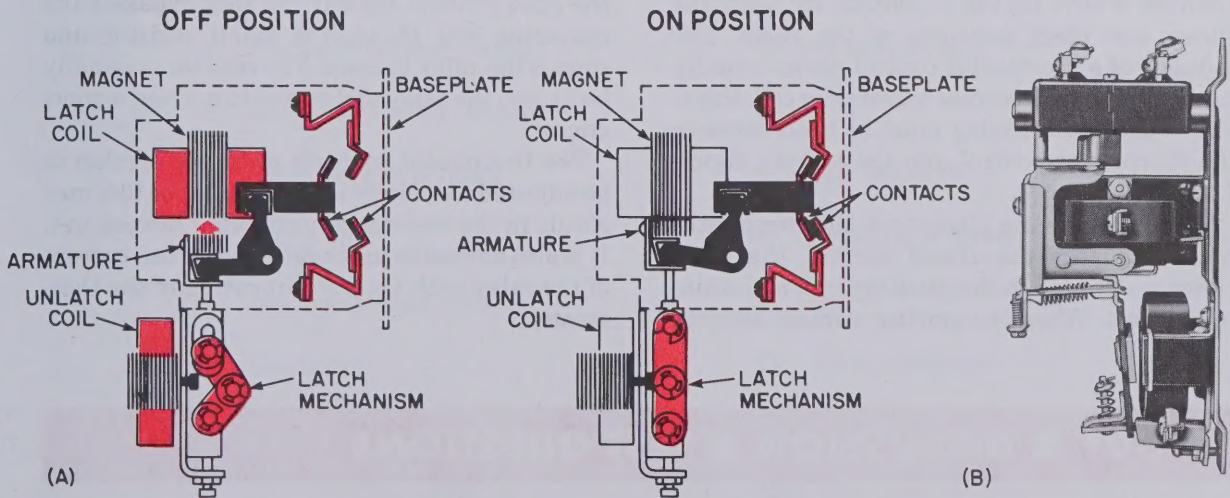


FIG. 7-16 Two types of latched-in or mechanically held relays in service. The upper coil is energized momentarily to close contacts, and the lower coil is energized momentarily to open the contact circuit. The momentary energizing of the coil is an energy-saving feature. (Courtesy Square D Co.)

where a sequence of operations must continue from the point of interruption after power is resumed — rather than return to the beginning of the sequence. Quiet operation of contactors and relays is required in many control systems used in hospitals, schools, and office buildings. Mechanically held contactors and relays are generally used in locations where the slight hum, characteristic of alternating-current magnetic devices, is objectionable.

In addition, mechanically held relays are often used in machine tool control circuits. These relays can be latched and unlatched through the operation of limit switches, timing relays, starter interlocks, timeclocks, photoelectric cells, other control relays, or push buttons. Generally, mechanically held relays are available in 10- and 15-ampere sizes; mechanically held contactors are also available in sizes ranging from 30 amperes up to 1200 amperes.

THERMOSTAT RELAY

Thermostat-type relays, figure 7-17, are used with three-wire, gauge-type thermostat controls or other pilot controls having a slowly moving element which makes a contact for both the closed and open positions of the relay. The contacts of a thermostat control device usually cannot handle the current to a starter coil; therefore, a thermostat relay must be used between the thermostat control and the starter, figure 7-18.

When the moving element of the thermostat control touches the closed contact, the relay closes and is held in this position by a maintaining contact. When the moving element touches

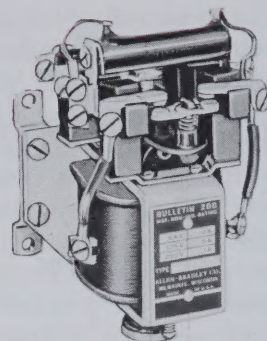


FIG. 7-17 Thermostat relay (Courtesy Allen-Bradley Co.)

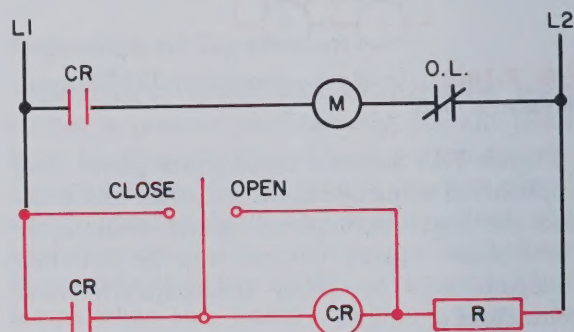


FIG. 7-18 Starter coil (M) is controlled by thermostat relay.

the open contact, the current flow bypasses the operating coil through a small resistor and causes the relay to open. The resistor is usually built into the relay and serves to prevent a short circuit.

The thermostat contacts must not overlap or be adjusted too closely to one another as this may result in the resistance unit being burned out. It is also advisable to compare the inrush current of the relay with the current rating of the thermostat.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What are control relays? *Devices used to control - control relays*
 2. What are typical uses for control relays? *operate callioads, pilot lights, motor starters*
- Small amounts of current*

3. Why are contactors described as both control pilot devices and large magnetic switches controlled by pilot devices? *They handle more current*
4. What is the principal difference between a contactor and a motor starter? *Overload Protection*
5. What causes the arc to move upward in a blowout magnet? *Magnetic field*
6. Why is it desirable to extinguish the arc as quickly as possible? *prolong contact life*
7. What will happen if the terminals of the blowout coil are reversed? *Arc will not extinguish*
8. Why will the blowout coil also operate on ac? *Magnetic field are reversed*
9. What are the advantages of a mechanically held relay? *less noise - less current - coil life*
10. Why are mechanically held relays energy-saving devices? *No electricity*
11. Why does coil (CR) in figure 7-18 drop out when the thermostat touches the open position?
12. Match each item in the left-hand column with the appropriate item in the right-hand column.

a. Double-break contact

1. 

b. Relay

2. 

c. Magnetic blow-out coil

3. 

d. Single pole, double throw

4. 

e. Normally closed contact

5. arc suppression

f. Latched-in relay control

6. 

g. Single-break contact

7. 0.15 amperes

h. Relay coil

8. three-phase power

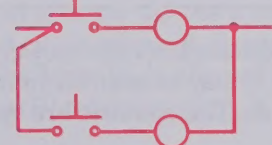
i. Normally open contact

9. 

j. Contactor

10. 1200 Amperes

11. 

12. 

UNIT 8 *Timing Relays*

Objectives After studying this unit, the student will be able to:

- Identify the primary types of timing relays
- Explain the basic steps in the operation of the common timing relays
- List the factors which affect the selection of a timing relay for a particular use
- List applications of several types of timing relays
- Draw simple circuit diagrams using timing relays
- Identify *on* and *off* delay timing wiring symbols

INTRODUCTION

A timing relay is similar to a control relay, except that certain of its contacts are designed to operate at a preset time interval, or time lag, after the coil is energized, or de-energized.

Many industrial control applications require timing relays that can provide dependable service and are easily adjustable over the timing ranges. The proper selection of timing relays for a particular application can be made after a study of the service requirements and with a knowledge of the operating characteristics inherent in each available device. A number of timing devices are manufactured with features suitable for a wide variety of applications.

FLUID DASHPOT TIMING RELAYS

Magnetically operated, oil dashpot-type timing relays, figure 8-1, may be used on voltages up to 600 volts ac or dc. The contacts are operated by

the movement of an iron core. The magnetic field of a solenoid coil lifts the iron core against the retarding force of a piston moving in an oil-filled dashpot. This type of relay is not very accurate. The piston must be allowed to settle back down to the bottom of the dashpot between successive timing periods. If the piston is not allowed to make a full return, the timing is erratic. The dashpot timing relay provides time delay after the magnet is energized. The contact may be normally open or normally closed for different applications.

Unlike the magnetic overload relay, the dashpot timing relay operates with a potential coil connected across the line through contacts or switches. The overload relay operates with a current coil that is affected by the motor current load.

Fluid dashpot timing relays are used for a number of applications:

- to control the accelerating contactors of motor starters

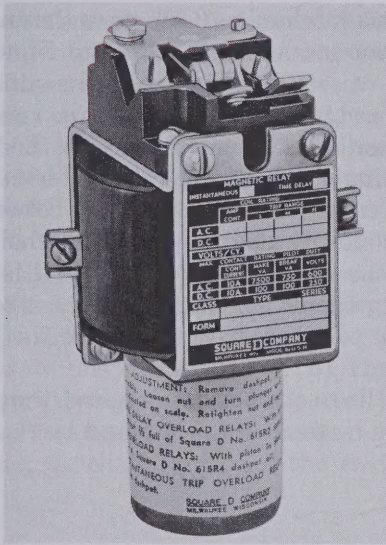


FIG. 8-1 Fluid dashpot timing relay (Courtesy square D Co.)

- to time the closing or opening of valves on refrigeration equipment
- for any application where the operating sequence requires a delay.

It is not necessary that the elapsed time of the delay be extremely accurate.

These relays use a silicone dashpot fluid which is not an oil. The fluid helps to eliminate the effect of varying viscosity on the timing due to changes in ambient temperature. The silicone fluid operates successfully in an ambient temperature range of $+120^{\circ}\text{F}$ to -30°F ($+48.9^{\circ}\text{C}$ to -34.4°C). The timing range can be adjusted easily from two seconds to 30 seconds.

Multicontact dashpot timing relays are used for dc motor starting. When the coil is energized on this type of timing relay, the contacts close in succession with a time lag between each closing.

PNEUMATIC TIMERS

The construction and performance features of the pneumatic (air) timer make it suitable for

the majority of industrial applications. Pneumatic timers have the following characteristics:

- unaffected by normal variations in ambient temperature or atmospheric pressure
- adjustable over a wide range of timing periods
- good repeat accuracy
- available with a variety of contact and timing arrangements.

This type of relay has a pneumatic time-delay unit that is mechanically operated by a magnet structure. The time-delay function depends upon the transfer of air through a restricted orifice by the use of a reinforced synthetic rubber bellows or diaphragm. The timing range is adjusted by positioning a needle valve to vary the amount of orifice or vent restriction.

The process of energizing or de-energizing pneumatic timing relays can be controlled by pilot devices such as push buttons, limit switches, or thermostatic relays. Since the power drawn by a timing relay coil is small, sensitive control devices may be used to control the operating sequence.

Pneumatic timing relays are used for motor acceleration and in automatic control circuits. Automatic control is necessary in applications where repetitive accuracy is required, such as controls for machine tools and control of sequence operations, industrial process operation, and conveyor lines.

Pneumatic timers provide time delay through two arrangements. The first, *on-delay*, means that the relay provides time delay when it is *energized*; the second arrangement, *off-delay*, means the relay is *de-energized* when it provides time delay. Figure 8-2A is a typical pneumatic timer attachment. Figure 8-2B is the cross section of a different pneumatic timer.

In the on-delay arrangement, when the operating coil (O) is energized, solenoid action raises the solenoid plunger (A). As a result, the pressure on rod (B) is released. Spring (W), located inside the bellows (E), is allowed to push rod (B) upward. As (B) moves upward, it causes the off-

of the reset spring. The downward movement of the plunger forces (B) down, thus resetting the timer almost instantaneously.

In the off-delay arrangement, with this manufacturer, the solenoid in figure 8-2 is rotated 180°. This means that when the operating coil (O) is energized, plunger (A) is held down, and (G) pushes against (B), holding the bellows (E) in a fully compressed position.

When the operating coil is de-energized, the reset spring forces (A) to rise. (G) also rises and releases the downward force on (B). The bellows (E) slowly expands, forcing (B) upward. As in the on-delay arrangement, as (B) moves up it trips to toggle, which in turn trips the switch.

TIMED CONTACTS

Table 8-1 illustrates standard diagram symbols for timed contacts. These symbols are used by manufacturers and others in wiring diagrams. The first symbol from left to right, represents a normally open contact (when the relay is de-energized). When the relay is energized, there is a time delay in closing (on-delay). Thus, it is a normally open, timed closing (N.O.T.C.) contact. Similarly, the second symbol is for a normally closed contact. After the relay coil is energized, there is a time delay before this contact opens

TABLE 8-1 Standard elementary diagram symbols for timed contacts

TIMED CONTACTS – CONTACT ACTION RETARDED AFTER COIL IS:			
Energized		De-energized	
N.O.T.C.	N.C.T.O.	N.O.T.O.	N.C.T.C.
			
On Delay		Off Delay	

(N.C.T.O.). The third symbol is for a normally open contact, at rest. When the relay coil is energized, this contact closes instantly. It will stay closed as long as the coil is energized. When the coil is de-energized, there is a time delay before the contact opens (N.O.T.O.). This mode is called off delay. The last symbol represents a normally closed timing contact. When the timer coil is energized, this contact opens rapidly and remains open. When current to the coil is disconnected, there is a time delay before the contact closes to its normal position.

INSTANTANEOUS CONTACTS

Most pneumatic timers may have non-timed contacts in addition to timing contacts. These nontimed contacts are controlled directly by the timer coil, as in a general-purpose control relay. These auxiliary contacts are often used on pneumatic timers to combine the functions of a standard or conventional control relay and a timing relay. The regular, or instantaneous contacts, are easily installed, or added, to the timer on the job site.

MOTOR-DRIVEN TIMERS

When a process has a definite on and off operation, or a sequence of successive operations, a motor-driven timer is generally used, figures 8-3 and 8-4. A typical application of a motor-driven timer is to control laundry washers where the loaded motor is run for a given period in one direction, reversed, and then run in the opposite direction. Motor-driven timers are also used where infrequent starting of large motors is required.

Generally, this type of timer consists of a small, synchronous motor driving a cam-dial assembly on a common shaft. A motor-driven timer successively closes and opens switch contacts which are wired in circuits to energize control relays or contactors to achieve desired operations.

Min. Time Delay: 0.05 second

Max. Time Delay: 3 minutes

Minimum Reset Time: .075 second

Accuracy: ± 10 percent of setting

Contact Ratings:

Ac

6.0 A, 115 V

3.0 A, 230 V

1.5 A, 460 V

1.2 A, 550 V

Dc

1.0 A, 115 V

0.25 A, 230 V

Operating Coils: Coils can be supplied for voltages and frequencies up to 600 volts, 60 hertz ac and 250 volts dc

Types of Contacts: One normally open and one normally closed. Cadmium silver alloy contacts.

FIG. 8-3 Typical specifications

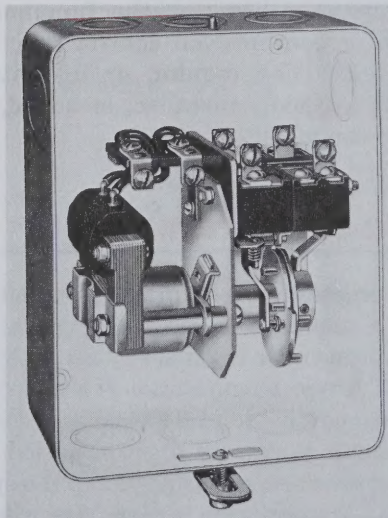


FIG. 8-4 Motor-driven process timer in a general-purpose enclosure (Courtesy Allen-Bradley Co.)

DC SERIES RELAY

Generally, the name of a relay is descriptive of its major purpose, construction, or principle of operation. A common application of dc series

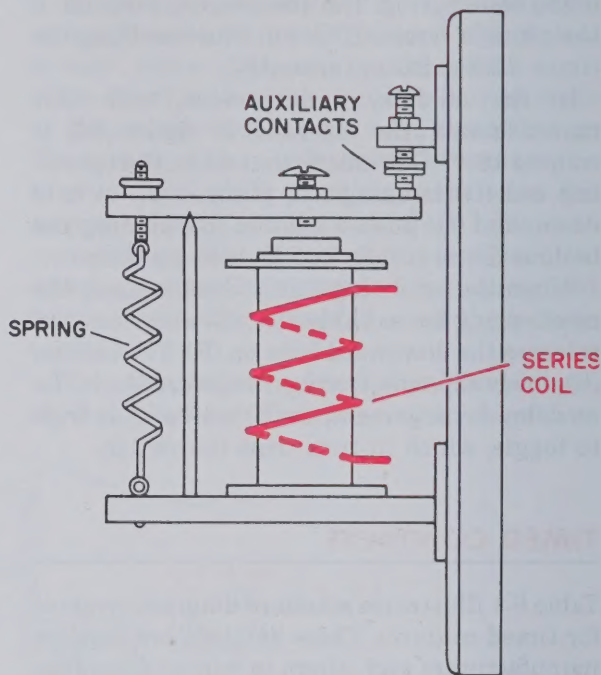


FIG. 8-5 Series type relay

relays is to time the acceleration of dc motors. For example, the coil of the dc series relay, figures 8-5 and 8-6, is connected in series with the starting resistance so that the starting current of the motor passes through it. The contacts of the series relay are connected to an auxiliary circuit.

The relay contacts shown in figure 8-5 are usually connected to control the coils of a magnetic contactor. The armature is light and constructed so that it is very fast in operation. As the starting current passes through the coil, the armature is pulled down (overcoming the resistance of a spring), causing small contacts to open. When the current in the coil has decreased to a predetermined value, the spring pulls the armature back and the contacts close. The value of current at which the coil loses control of the armature is determined by the spring setting.

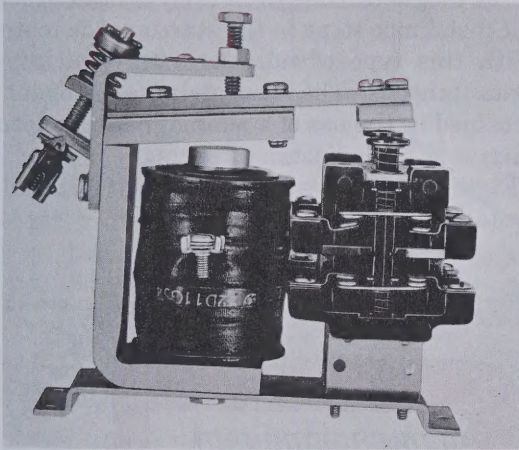


FIG. 8-6 Dc series relay (Courtesy General Electric Co.)

DC SERIES MAGNETIC LOCKOUT CONTACTOR

The dc series lockout relay, figure 8-7, consists of two coils connected in series. One coil, the lockout coil, acts to hold the contactor open. The other coil, the pull-in coil, acts to close the contactor. The pull-in coil is almost saturated at low-current values.

The current through the pull-in coil is the same as the current through the lockout coil. As a result, when the magnetic pull of one coil changes, the pull on the other coil will change also. However, since the closing (pull-in) coil has a relatively large amount of iron in its magnetic circuit, the current-torque curve of the closing coil is represented by curve C of figure 8-8. Due to the small amount of iron in the magnetic circuit of the lockout coil, the current-torque curve of the lockout magnet is represented by curve L of figure 8-8.

If the value of the motor-starting current is larger than b in figure 8-8, then the torque of the lockout coil predominates. When the motor accelerates and the current falls below the value b , the lockout coil loses control and the torque of the closing coil gains control.

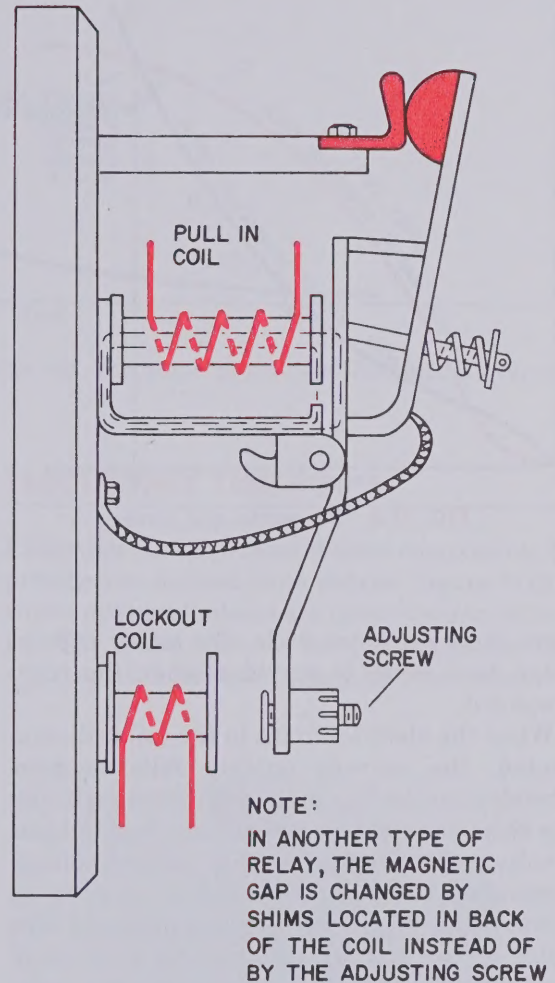


FIG. 8-7 Dc series magnetic lockout contactor

MAGNETIC TIME LIMIT RELAY

If current is increasing in a coil, then the emf due to self-induction acts in a direction to oppose the increase of current in that coil. If a current is decreasing in a coil, the emf due to self-induction in the coil acts in a direction to oppose the decrease of current in the coil.

One type of magnetic time limit relay has a single coil wound on a hollow copper cylinder containing an iron core. Other time limit relays

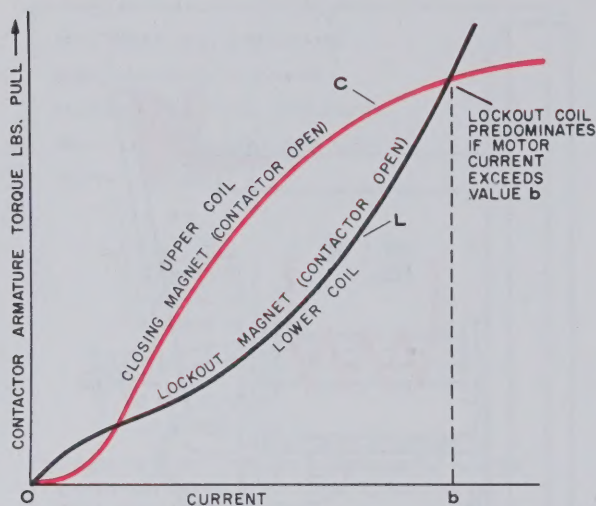


FIG. 8-8 Current-torque curves

have copper-jacketed coils. For either type of relay, time delay is provided when the relay drops out.

When the electric circuit in the coil is disconnected, the current quickly falls to zero. Therefore, as the flux in the coil decreases, it cuts the short-circuited copper cylinder and induces a voltage in the cylinder. This induced voltage sends a current through the copper cylinder. As a result of this current, a flux is produced that holds up the magnet armature for a period of time after the coil circuit is broken. The delay time is limited by the number of turns on the coil and the amount of iron in the circuit.

Figure 8-9 is a sketch of a magnetic time limit relay. When the relay is energized, the armature (M) is drawn against the core (N). At the same time, the tension of the spring tends to draw the armature away from the core. As the flux maintained by the current in the copper sleeve dies away, the time at which the armature is released depends to some degree on the tension of the spring. The release time also can be varied by inserting a bronze shim in the gap between M and N; the thicker the shim, the lower the flux, and the sooner the armature is released.

The magnetic time limit relay is used to short out resistance steps in the startup of dc motors. With this type of relay armature, pickup is instantaneous. The time delay at dropout is obtained by the use of a nonmagnetic armature shim and the adjustment spring.

Figure 8-10 shows a larger capacity dc timing contactor.

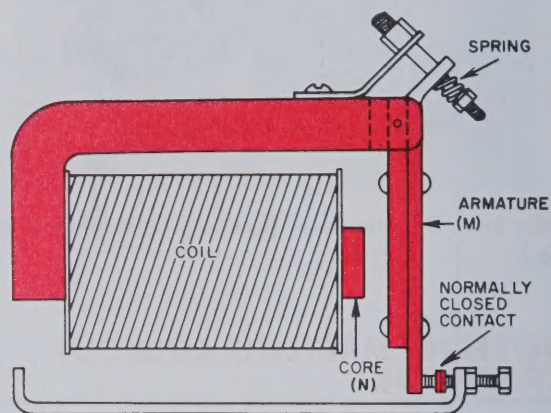


FIG. 8-9 Dc magnetic time limit relay

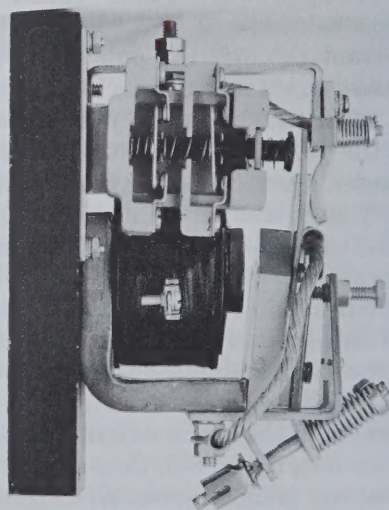


FIG. 8-10 Time-delay contactor (Courtesy General Electric Co.)

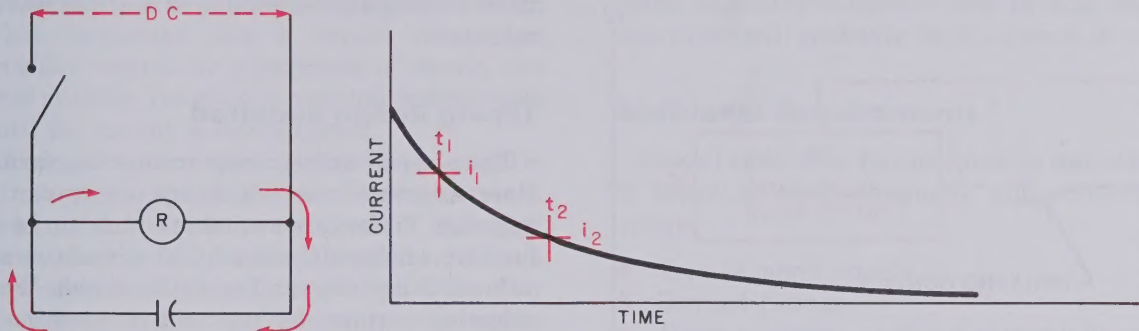


FIG. 8-11 Charged capacitor discharging through a relay coil. The graph at the right illustrates the current decrease in the coil.

CAPACITOR TIME LIMIT RELAY

Assume that a capacitor is charged by connecting it momentarily across a dc line and then the capacitor dc is discharged through a relay coil. The current induced in the coil will decay slowly, depending on the relative values of capacitance, inductance, and resistance in the discharge circuit.

If a relay coil and a capacitor are connected in parallel to a dc line, figure 8-11, the capacitor is charged to the value of the line voltage and a current appears in the coil. If the coil and capacitor combination is now removed from the line, the current in the coil will start to decrease along the curve shown in figure 8-11.

If the relay is adjusted so that the armature is released at current i_1 , a time delay of t_1 is obtained. The time delay can be increased to a value of t_2 by adjusting the relay so that the armature will not be released until the current is reduced to a value of i_2 .

A potentiometer is used as an adjustable resistor to vary the time. This resistance-capacitance (RC) theory is used in industrial electronic and solid-state controls also. This timer is highly accurate and is used in motor acceleration control and in many industrial processes.

ELECTRONIC TIMERS

Electronic timers use solid-state components to provide the desired time delays. Figure 8-12A shows a typical solid-state timer used in industry. The timed contacts are located at the top right, and the instantaneous contacts are located

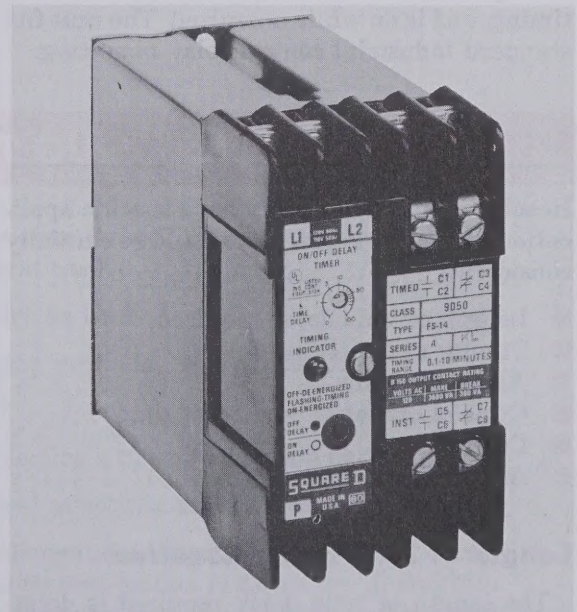


FIG. 8-12(A) Solid-state industrial timing relay (Courtesy Square D Co.)

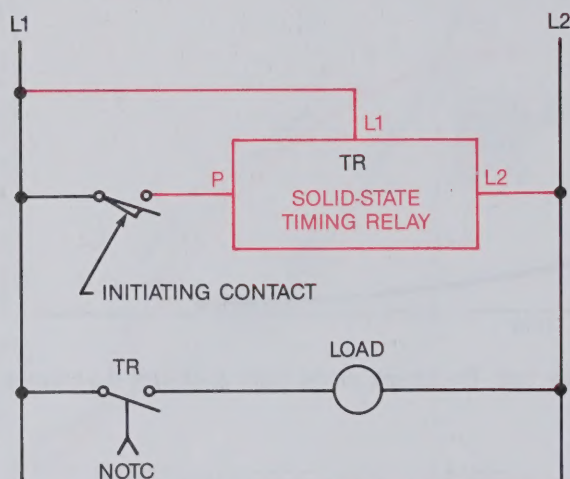


FIG. 8-12(B) Typical elementary diagram for a solid-state timer as shown in figure 8-12(A)

at the bottom right. The wiring terminals are clearly marked. An elementary diagram for this timer is shown in figure 8-12B.

The timer has a lighted timing indicator. It is a light-emitting diode (LED) that is off when the timing relay is de-energized, flashes while timing, and is on while energized. The unit fits standard industrial control relay mounting.

SELECTING A TIMING RELAY

In selecting a timing relay for a specific application, the following factors should be carefully considered.

- Length of time delay required
- Timing range required
- Allowable error
- Cycle of operation and reset time
- Cost
- Additional requirements

Length of Time Delay Required

The length of time delay required is determined by the type of machine or process that the timer will control. This time delay will range

from a fraction of a second to as much as several minutes.

Timing Range Required

The phrase timing range means the various time intervals over which the timer can be adjusted. Timers are available which can be set for a time delay of 1 second, 100 seconds, or any value of delay between 1 and 100 seconds. When selecting a timer for use with a machine or process, the range should be wide enough to handle the various time-delay periods that may be required by the machine or process.

The exact timing value for any position within the timing range must be found by trial and error. A scale provided with a timer is intended primarily to permit a quick reset of the timer to the timing position previously determined to be correct for a given operation.

Allowable Error

All timers are subject to some error; that is, there may be a plus or minus time variation between successive timing operations for the same setting. The amount of error varies with the type of timer and the operating conditions. The error is usually stated as some percentage of the time setting.

The percentage of error for any timer depends on the type of timer, the ambient temperature (especially low temperatures), coil temperature, line voltage, and the length of time between operations.

Cycle of Operation Required and Reset Time

For one type of timer, the timer becomes operative when an electrical circuit opens or closes. A time delay then occurs before the application process begins. As soon as the particular process action is complete, the timer circuit resets itself. The circuit must be energized or de-energized each time the timing action is desired.

A second type of timer is called a process timer. When connected into a circuit, this timer provides control for a sequence of events, one after another. The cycle is repeated continuously until the circuit is de-energized.

An important consideration in the selection of a timer is the speed at which the timer resets. Reset time is the time required for the relay mechanism to return to its original position. Some industrial processes require that the relay reset instantaneously. Other processes require a slow reset time. The reset time varies with the type of timing relay and the length of the time delay.

Cost

When there are several electromagnetic timers that meet the requirements of a given application, it is advisable to select the timer with the smallest number of operating parts. In other

words, select the simplest timer. In most cases, this timer will probably be the lowest in cost.

Additional Requirements

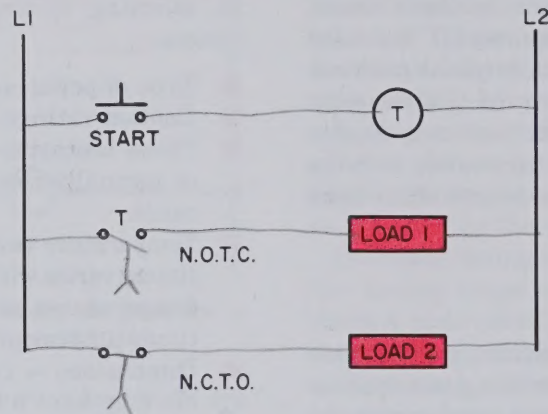
Several additional factors must be considered in selecting electromagnetic and solid-state timers:

- Type of power supply.
- Contact ratings.
- Timer contacts — a choice of normally open or normally closed contacts usually can be made.
- Temperature range — the accuracy of some timers varies with the temperature; however, temperatures below freezing may affect the timer accuracy.
- Dimensions — the amount of space available may have a bearing on the selection of a timer.

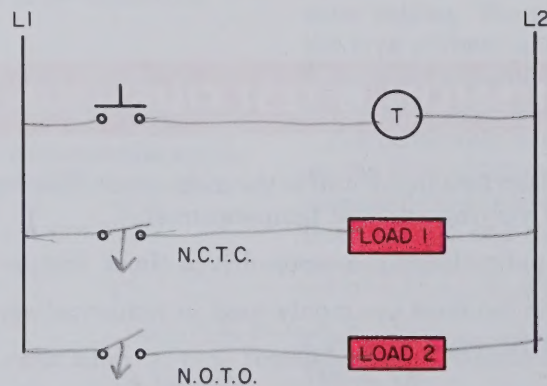
STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Which timer described in the unit is the most erratic? How may its timing period be affected by varying ambient temperatures? *Dash Pot Viscosity of F*
2. List several applications for a motor-driven timer. *Time clock - Washer - Oiler*
3. Which timer is the most commonly used in industrial applications? *pneumatic*
4. How is the pneumatic timer adjusted? *Needle Valve*
5. List six factors to be considered when selecting a timing relay for a particular use. *Price - Accuracy - Range - Time - Reset Time - Contact Ratings*
6. List several additional factors which will affect the selection of a timing relay. *Size - Temperature*
7. On a separate sheet of paper, draw an elementary diagram of a fractional horsepower, manual motor starter. When the starter contact is closed it will energize a pneumatic timing relay coil through the overload heater. After the timer coil is energized, the circuit will show a delayed closing contact that energizes a small motor on 120 volts.

8. Connect these components in the following sketch:
- The start push button to the timer coil
 - Load 1 to N.O.T.C.
 - Load 2 to N.C.T.O.
 - Show proper symbols



9. Connect the following components:
- Start push button to the timer coil
 - Load 1 to N.C.T.C.
 - Load 2 to N.O.T.O.
 - Show proper symbols



UNIT 9 Pressure Switches and Regulators

Objectives After studying this unit, the student will be able to:

- Describe how pressure switches, vacuum switches, and pressure regulators may control motors
- List the adjustments which can be made to pressure switches
- Identify wiring symbols used for pressure switches

Any industrial application which has a pressure sensing requirement can use a pressure switch, figure 9-1A. Figure 9-1B shows the internal construction of a typical pressure switch. A large variety of pressure switches are available to cover the wide range of control requirements for pneumatic or hydraulic machines such as welding equipment, machine tools, high pressure lubricating systems, and motor-driven pumps and air compressors.

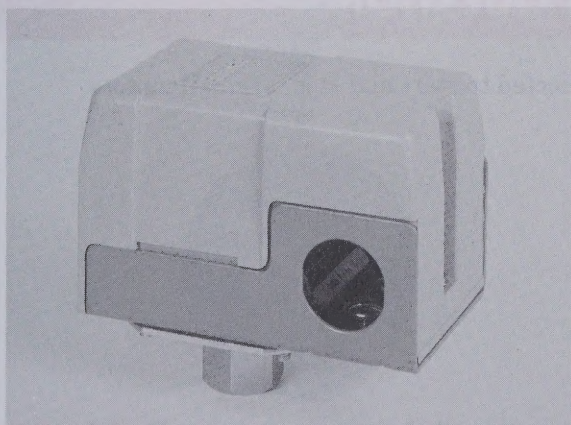


FIG. 9-1(A) Exterior view of a pressure switch (Courtesy of Furnas Electric Company)

The pressure ranges over which pressure switches can maintain control also vary widely. For example, a diaphragm-actuated switch can be used when a sensitive response is required to small pressure changes at low-pressure ranges,

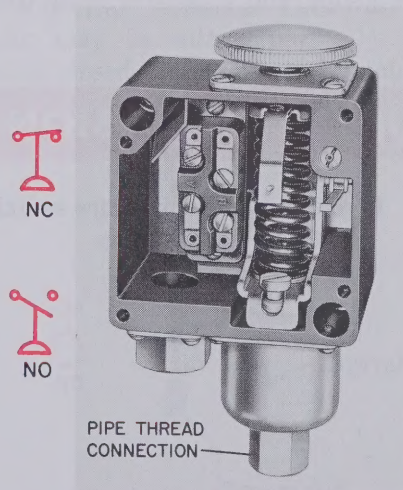


FIG. 9-1(B) Industrial pressure switch with cover removed. Note operating knob. Also note wiring diagram symbols for normally closed and normally open contacts. (Courtesy Square D Co.)

figure 9-2. A metal bellows-actuated control is used for pressures up to 2000 pounds per square inch. Piston-operated hydraulic switches are suitable for pressures up to 15,000 psi. In all of these pressure controlled devices, a set of contacts is operated.

The most commonly used pressure switches are single-pole switches. Two-pole switches are also used for some applications. Field adjustments of the range and the differential pressure (or the difference between the cut-in and cut-out pressures) can be made for most pressure switches. The spring pressure determines the pressures at which the switch closes and opens its contacts.

Pressure regulators provide accurate control of pressure or vacuum conditions for systems. When they are used as pilot control devices with magnetic starters, pressure regulators are able to control the operation of liquid pump or air compressor motors in a manner similar to that of pressure switches. Reverse action regulators can be used on pressure system interlocks to prevent the start of an operation until the pressure in the system has reached the desired level.

Pressure regulators consist of a Bourdon-type pressure gauge and a control relay. Delicate

contacts on the gauge energize the relay and cause it to open or close. The relay contacts are used to control a large motor starter in order to avoid damage or burning of the gauge contacts. Standard regulators will open a circuit at high pressure and close it at low pressure. Special reverse operation regulators will close the circuit at high pressure and open the circuit at low pressure.

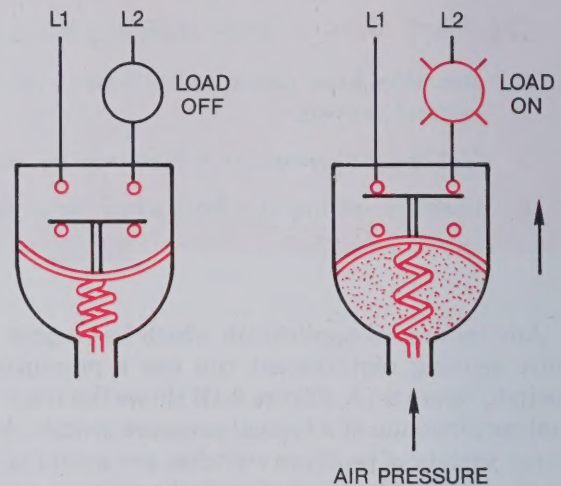


FIG. 9-2 Simplified pressure switch control

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Describe how pressure switches are connected to start and stop (a) small motors and (b) large motors.

UNIT 10 Float Switches

Objectives After studying this unit, the student will be able to:

- Describe the operation of float switches
- List the sequence of operation for sump pumping or tank filling
- Draw wiring symbols for float switches

A float switch is used when a pump motor must be started and stopped according to changes in the water (or other liquid) level in a tank or sump. Float switches are designed to

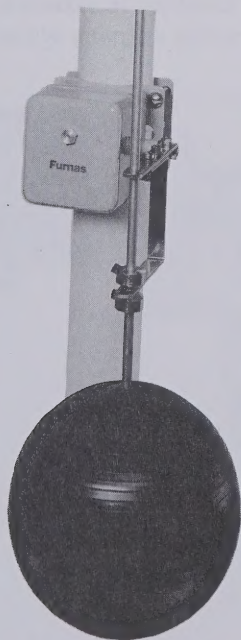


FIG. 10-1 Float switch complete with bracket, rod, and ball (Courtesy of Furnas Electric Company, Batavia, IL)

provide automatic control of ac and dc pump motor magnetic starters and automatic direct control of light motor loads.

The operation of a float switch is controlled by the upward or downward movement of a float placed in a water tank. The float movement causes a rod operated, figure 10-1, or chain and counterweight, figure 10-2, assembly to open or close electrical contacts. The float switch contacts may be either normally open or normally closed and may not be submerged.

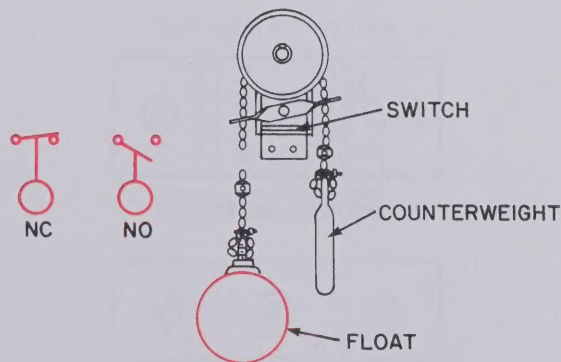


FIG. 10-2 Chain-operated float switch with normally closed (NC) and normally open (NO) wiring symbols

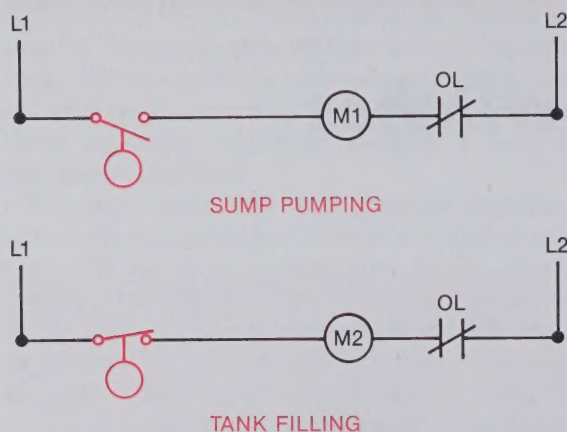


FIG. 10-3 Control circuits for a float switch

Float switches may be connected to a pump motor for tank or sump pumping operations or tank filling, depending on the contact arrangement. See figure 10-3 for the elementary wiring circuits.

Electronic methods of control may be used in place of the basic float switch for liquid level control. These methods include electrode sensing, electronic wave transmission and detection, and other combinations.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Describe the sequence of operations required to (a) pump sumps and (b) fill tanks.

UNIT 11 Flow Switches

Objectives After studying this unit, the student will be able to:

- Describe the purpose and functions of flow switches
- Connect a flow switch to other electrical devices
- Draw and read wiring diagrams of systems using flow switches

A flow switch is a device which can be inserted in a pipe so that when liquid or air flows against a part of the device called a paddle, a switch is activated (figure 11-1). This switch either closes or opens a set of electrical contacts. The contacts may be connected to energize motor starter coils,

relays, or indicating lights. In general, a flow switch contains both normally open and normally closed electrical contacts, figure 11-2.

Figure 11-3 shows a flow switch installed in a pipe line tee. Half couplings are welded into larger pipes for flow switch installations.

Typical applications of flow switches are shown in figures 11-4 through 11-8. These applications are commonly found in the chemical and petroleum industries. Vaporproof electrical connections must be used with vaporproof switches. The insulation of the wire leading to

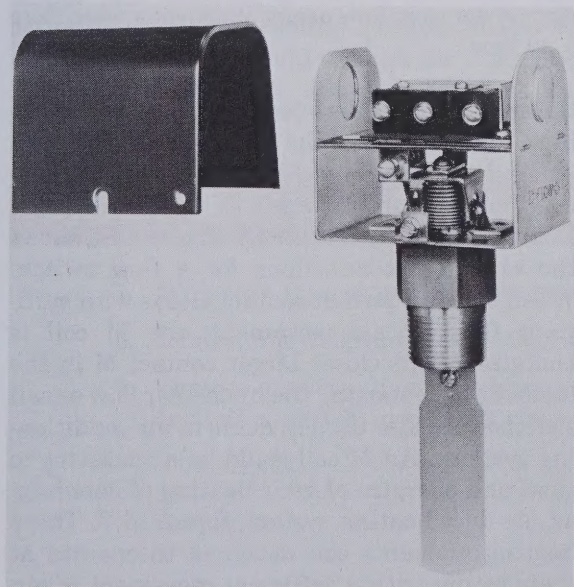


FIG. 11-1 Flow switch (Courtesy McDonnell & Miller ITT, Fluid Handling Division)

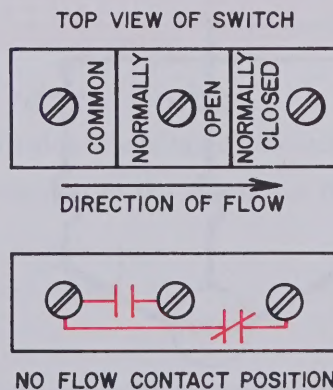


FIG. 11-2 Typical electrical terminals and contact arrangement of a flow switch

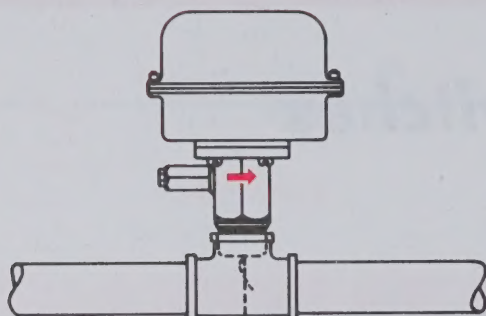


FIG. 11-3 Fluid flow switch installed

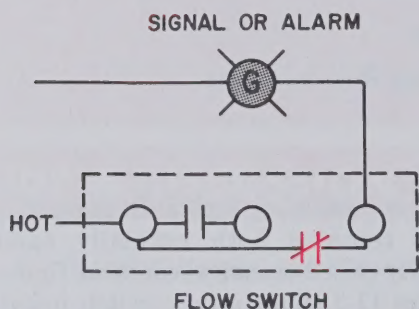


FIG. 11-5 Flow switch used to sound alarm or light signal when there is no flow using normally closed contacts

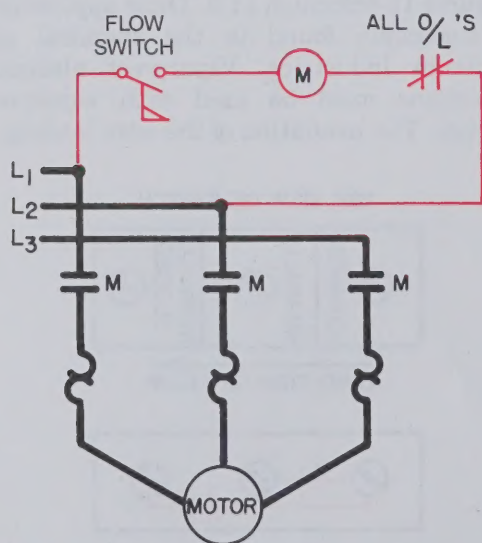


FIG. 11-7 Flow switch used with three-phase circuit; starts motor when flow occurs, stops motor when there is no flow

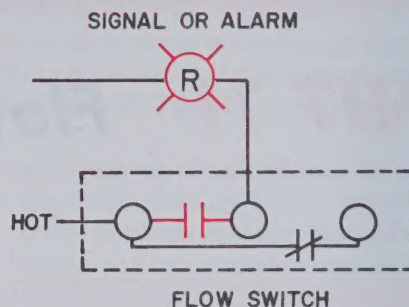


FIG. 11-4 Flow switch used to sound alarm or light signal when flow occurs using normally open contacts

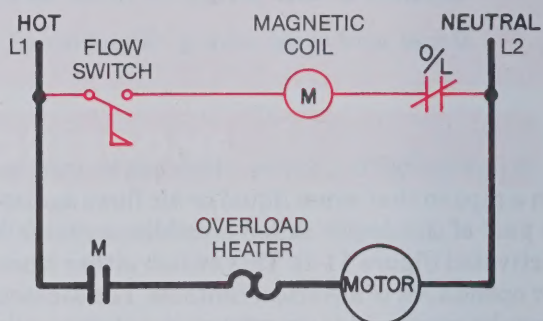


FIG. 11-6 Flow switch used with single-phase circuit; starts motor when flow occurs, stops motor when there is no flow

the switches must be adequate to withstand the high temperature of the liquid inside the pipe. (Consult the National Electric Code for insulation temperature ratings.)

The elementary diagram in figure 11-6 shows the electrical connections for a flow switch. When the flow switch contact closes with sufficient fluid or air movement, the M coil is energized. This closes larger contact M in the motor circuit, starting the motor. Air flow or sail switches are also used in ducts in air conditioning systems. An M coil could be a contactor to close and energize electric heating elements in an air duct heating system, figure 11-8. These heating elements are designed to operate at their rating with a sufficient movement of air. Without adequate air flow, the heating elements may burn out. The flow switch prevents this by

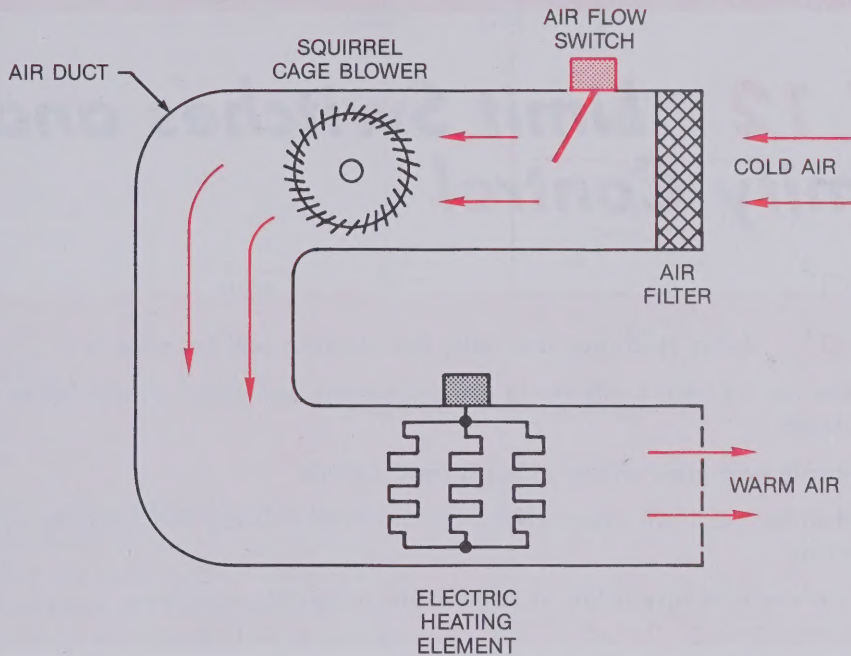


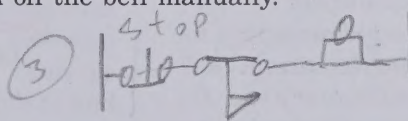
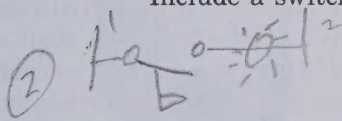
FIG. 11-8 An air duct heating system, flow switch controlled

detecting the air flow before energizing the heater and stopping it with a flow loss. The action is similar in cooling systems. Iced-over refrigeration coils would restrict air flow. The flow switch is used to detect insufficient air

movement over the refrigeration coils, stopping the refrigeration compressor and starting a defrost cycle. While the construction of air flow switches differs from that of liquid flow switches, the electrical connections are similar.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What are typical uses of flow switches?
2. Draw a line diagram to show that a green light will glow when liquid flow occurs.
3. Draw a one-line diagram showing a bell that will ring in the absence of flow. Include a switch to turn off the bell manually.



UNIT 12 Limit Switches and Proximity Control

Objectives After studying this unit, the student will be able to:

- Explain the use of limit switches in the automatic operation of machines and machine tools
- Wire a simple two-wire circuit using a limit switch
- Read and draw normally open (NO) and normally closed (NC) wiring symbols in simple circuit
- Explain the use and operation of solid-state proximity switches

LIMIT SWITCHES

The automatic operation of machinery requires the use of switches that can be activated by the motion of the machinery. The limit switch, figure 12-1, is used to convert this mechanical motion into an electrical signal to switch circuits. The repeat accuracy of the switches must be reliable and the response virtually instantaneous.

The size, operating force, stroke, and manner of mounting are all critical factors in the installation of limit switches due to mechanical limitations in the machinery. The electrical ratings of the switches must be carefully matched to the loads to be controlled.

The limit switch contacts should not be overloaded. Contacts must be selected according to the proper load, that is, the proper current and voltage, according to the manufacturer's specifications. Figure 12-2 shows the switch used to its capacity, and how it is used to control a load above its capacity by controlling a contactor to switch a heavier load.

In general, the operation of a limit switch begins when the moving machine or moving part of a machine strikes an operating lever which actuates the switch, figure 12-1. The limit

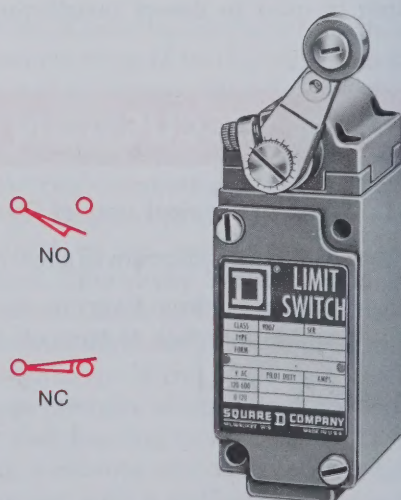


FIG. 12-1 Limit switch shown with wiring symbols (Courtesy Square D Co.)

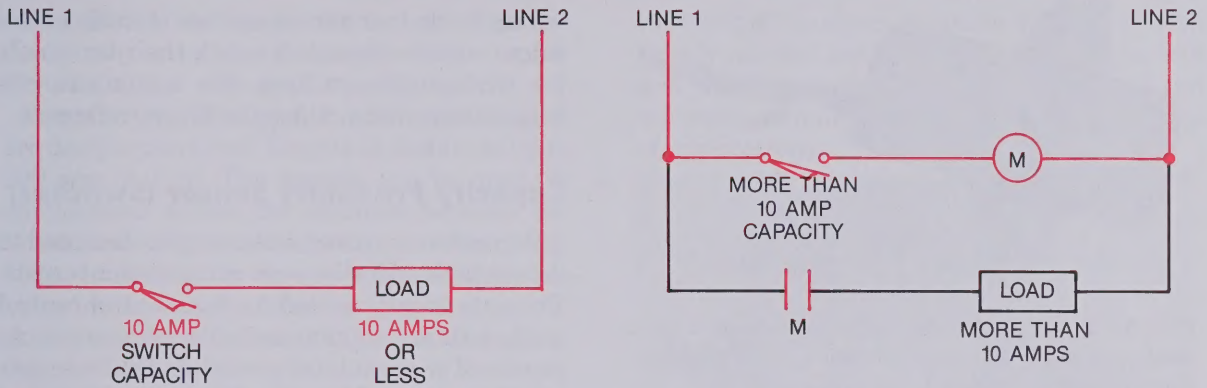


FIG. 12-2 Proper use of limit switches

switch, in turn, affects the electrical circuit controlling the machine and its movement.

Limit switches are used as pilot devices in the control circuits of magnetic starters to start, stop, speed up, slow down or reverse electric motors. Limit switches may be used either as control devices for regular operation or as emergency switches to prevent the improper functioning of machinery. They may be momentary contact (spring return) or maintained contact types. Most limit switches, as shown in figure 12-1, have normally open and normally closed contacts that are mechanically connected, or interlocked.

SOLID-STATE PROXIMITY SWITCHES

Solid-state proximity switches are a form of limit switch and photoelectric control. They are so called because they can be switched by a nearby or passing object. No physical contact is necessary to operate a proximity switch, as it is with a limit switch. These self-contained, two-wire devices are available in normally open or normally closed switching positions, both ac and dc. Figure 12-3 shows a simple, normally open proximity switch in a circuit. The switch can be connected in series or parallel. Figure 12-4 shows normally open and normally closed switch

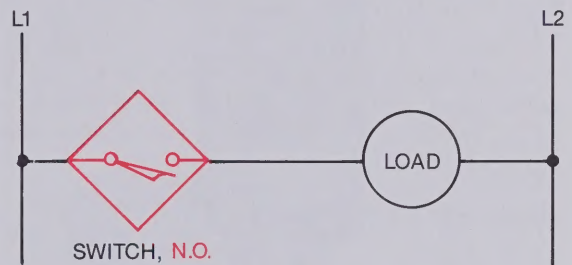


FIG. 12-3 Elementary diagram showing two-wire construction (ac or dc)

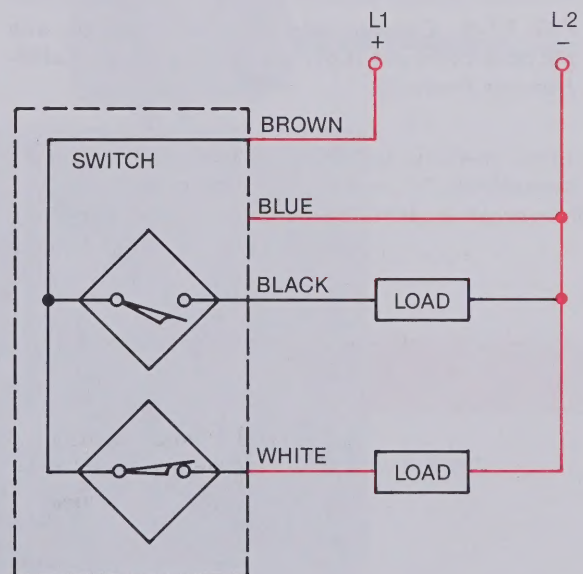


FIG. 12-4 Typical four-wire construction for dc, normally open and normally closed

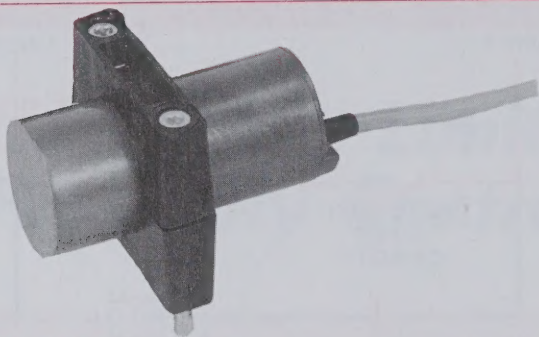


FIG. 12-5 Capacitive proximity sensor with a glass reinforced plastic housing (Courtesy of EATON Corp., Cutler-Hammer Products)

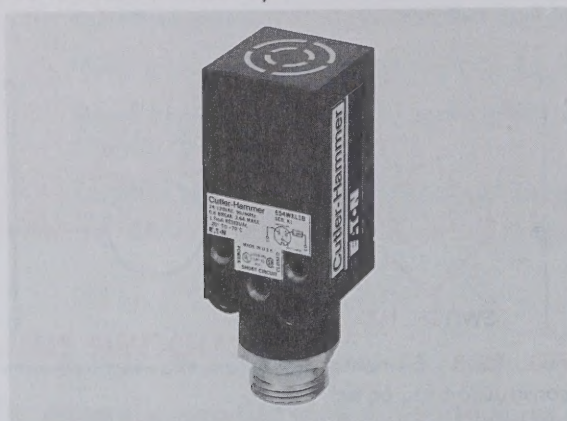


FIG. 12-6 Compact inductive proximity sensor with pin base connector (Courtesy EATON Corp., Cutler-Hammer Products)

wiring for dc, four-wire operation. Manufacturers color code or adequately mark their terminals for wiring. Always keep the manufacturer's installation instructions for future reference.

Capacity Proximity Sensor (Switches)

Capacitive proximity sensors are designed to detect both metallic and nonmetallic targets. They are ideally suited for liquid level control (such as float switch control) and for sensing powdered or granulated materials. For best operation, they should be used in an environment with relatively constant temperature and humidity. Figure 12-5 features glass-reinforced plastic housing capacitive sensors. Different shapes and mountings are available.

Inductive Proximity Sensors

Description. Compact inductive proximity sensors are also complete, self-contained switches. They are designed to detect the presence of all metals without making contact. Some models are quite elaborate and include light-emitting diodes (LEDs) to indicate "power on," "switch start," a "shorted condition," and when a "target is present." Figure 12-6 shows an inductive proximity sensor.

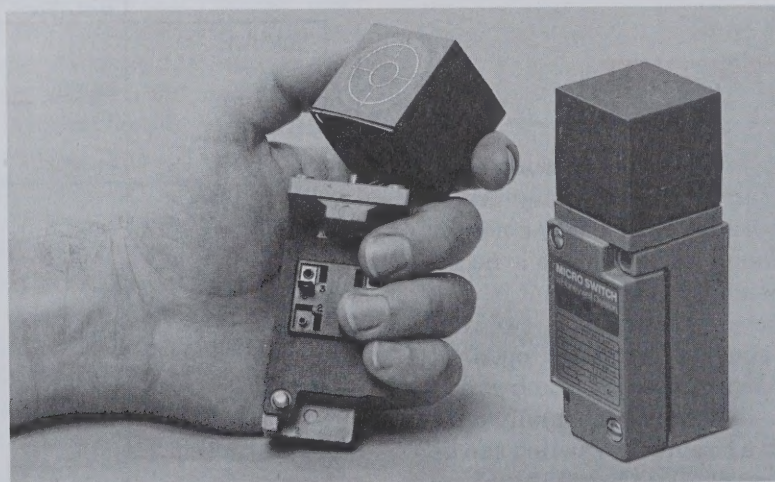


FIG. 12-7 Proximity sensor with rotating sensor head (Courtesy of MICRO SWITCH, A Honeywell Division)

The head of the sensor can be rotated in the field to any one of five sensing positions: top, or any one of four side positions, figure 12-7.

Pancake-type (low profile) solid-state sensors are designed to detect targets at distances up to 100 mm (4.0 in). The sensors can be used for applications where the distance between the sensor and target varies greatly or where long-distance sensing is required. The sensors are two-wire devices that can be corrected in the same manner as a mechanical limit switch, figure 12-8.

A solid-state cylindrical shaped proximity switch can be used in small or hard-to-reach places. This type of switch can be wired in series or parallel, figure 12-9.

The sensing head is mounted where the object is to be sensed. It is then wired to a chassis (amplifier/power supply). The chassis usually contains the electronic circuitry and a screw-driver slot for a sensitivity adjustment.

Operation. Inductive proximity switches operate on the eddy current principle. When a metal object moves into the electromagnetic field of the sensing head, eddy currents are induced in the object. This causes a change in the loading of the oscillator (electronics producing the field), which then operates the output device.

Application. Proximity switches are typically used on production assembly lines in the following ways: to detect metal objects through nonmetal barriers, where metal objects must be differentiated from nonmetal objects; where

touching of the objects must be avoided, as with freshly painted or highly polished parts; as void and jam detectors; for counting; in special and extreme environments; and in many other types of applications.



FIG. 12-8 Low-profile pancake-type inductive proximity sensor (Courtesy of EATON Corp., Cutler-Hammer Products)

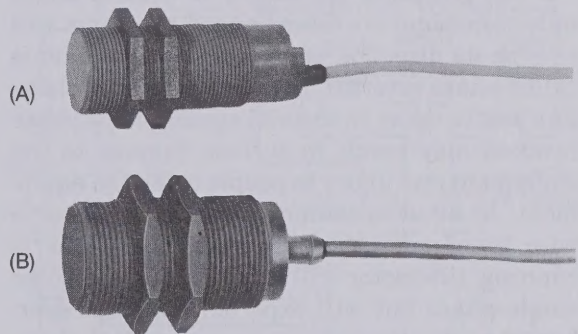


FIG. 12-9 Solid-state cylindrical proximity sensor (Courtesy of (A) EATON Corp., Cutler-Hammer Products, and (B) MICRO SWITCH, A Honeywell Division)

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Draw a simple circuit showing how a red pilot light is energized when a limit switch is operated by a moving object.
2. On what principle does an inductive proximity sensing unit work?



eddy currents

UNIT 13 Phase Failure Relays

Objectives After studying this unit, the student will be able to:

- Explain the purpose of phase failure relays
- List the hazards of phase failure and phase reversal
- Connect solid-state phase monitors

If two phases of the supply to a three-phase induction motor are interchanged, the motor will reverse its direction of rotation. This action is called phase reversal. In the operation of elevators and in many industrial applications, phase reversal may result in serious damage to the equipment and injury to people using the equipment. In other situations, if a fuse blows or a wire to a motor breaks while the motor is running, the motor will continue to operate on single phase but will experience serious overheating. To protect motors against these conditions, phase failure and reversal relays are used.

One type of phase failure relay, figure 13-1, uses coils connected to two lines of the three-phase supply. The currents in these coils set up a rotating magnetic field that tends to turn a copper disc clockwise. This clockwise torque actually is the result of two torques. One polyphase torque tends to turn the disc clockwise, and one single-phase torque tends to turn the disc counterclockwise.

The disc is kept from turning in the clockwise direction by a projection resting against a stop. However, if the disc begins to rotate in the counterclockwise direction, the projecting arm will move a toggle mechanism to open the line

contactors and remove the motor from the line. In other words, if one line is opened, the polyphase torque disappears and the remaining single-phase torque rotates the disc counterclockwise. As a result, the motor is removed from the line. In case of phase reversal, the polyphase

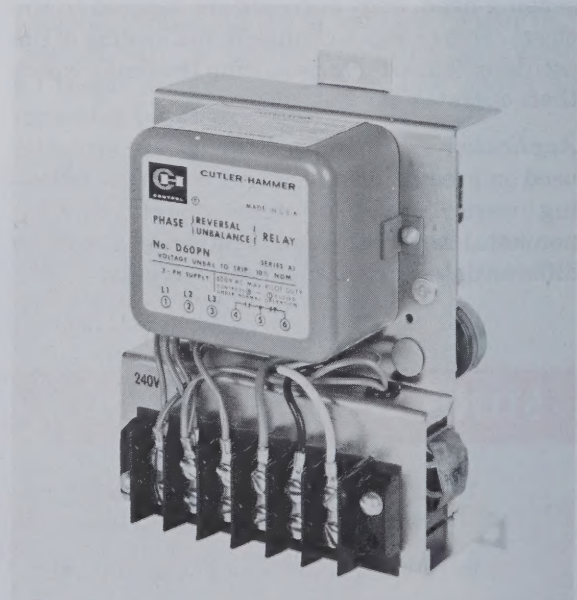


FIG. 13-1 Phase monitoring relay (Courtesy EATON Corp., Cutler-Hammer Products)

torque helps the single-phase torque turn the disc counterclockwise, and again, the motor is disconnected from the line.

Other designs of phase failure and phase reversal relays are available to protect motors, machines, and personnel from the hazards of open phase or reverse phase conditions. For example, one type of relay consists of a static, current-sensitive network connected in series with the line and a switching relay connected in the coil circuit of the starter. The sensing network continuously monitors the motor line currents. If one phase opens, the sensing network immediately detects it and causes the relay to open the starter coil circuit to disconnect the motor from the line. A built-in delay of five cycles prevents nuisance dropouts caused by fluctuating line voltages.

A solid-state phase monitoring relay is shown in figure 13-2. This relay provides protection in the event of a voltage unbalance or a phase reversal. The unit automatically resets after the correct voltage conditions return. Indicating lights show when the relay is activated. See the electrical connections in figure 13-3.

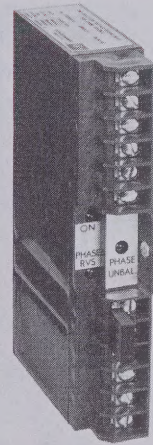


FIG. 13-2 Solid-state phase monitor relay (Courtesy EATON Corp., Culter-Hammer Products)

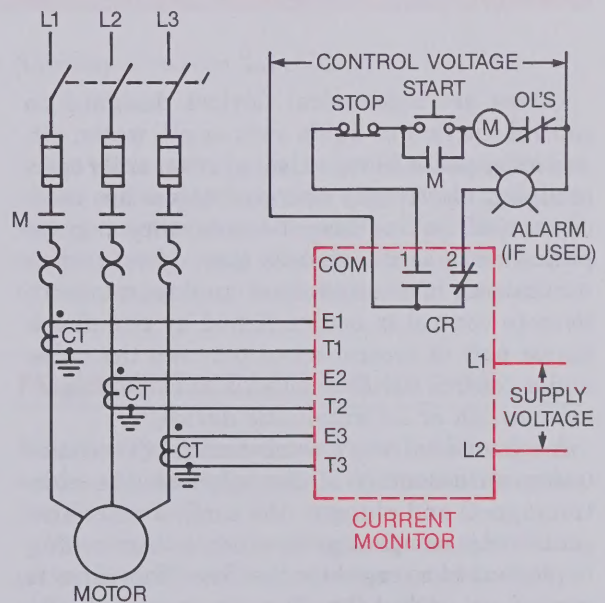


FIG. 13-3 Large motor solid-state current monitor connections

LARGE MOTOR CURRENT MONITOR

Figure 13-3 shows the elementary wiring diagram for large motor current monitoring. Current transformers are used for the input to the motor protector module. These modules, or relays, feature ambient temperature-compensated, solid-state overload protection, phase loss, phase reversal, locked motor rotor, and instantaneous fault protection. Terminal connections are clearly marked for proper installation.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What is the purpose of phase failure relays?
2. What are the hazards of phase failure and phase reversal?

Protect People & equipment

*Machine Reverses by itself
Over heating*

UNIT 14 Solenoid Valves

Objectives After studying this unit, the student will be able to:

- Describe the purpose and operation of two-way solenoid valves
- Describe the purpose and operation of four-way solenoid valves
- Connect and troubleshoot solenoid valves
- Read and draw wiring symbols for solenoid valves

Valves are mechanical devices designed to control the flow of fluids such as oil, water, air, and other gases. Many valves are manually operated, but electrically operated valves are most often used in industry because they can be placed close to the devices they operate, thus minimizing the amount of piping required. Remote control is accomplished by running a single pair of control wires between the valve and a control device such as a manually operated switch or an automatic device.

A solenoid valve is a combination of two basic units: an assembly of the solenoid (the electromagnet) and plunger (the core), and a valve containing an opening in which a disc or plug is positioned to regulate the flow. The valve is opened or closed by the movement of the magnetic plunger. When the coil is energized, the plunger (core) is drawn into the solenoid (electromagnet). The valve operates when current is applied to the solenoid. The valve returns automatically to its original position when the current ceases.

Most control pilot devices operate a single-pole switch, contact, or solenoid coil. The wiring diagrams of these devices are not difficult to

understand, and the actual devices can be connected easily into systems. It is recommended that the electrician know the *purpose* of and understand the *action* of the *total* industrial system for which various electrical control elements are to be used. In this way, the electrician will find it easier to design or assist in designing the electrical control system. It will also be easier for the electrician to install and maintain the control system.

TWO-WAY SOLENOID VALVES

Two way (in and out) solenoid valves, figure 14-1, are magnetically operated valves which are used to control the flow of Freon, methyl chloride, sulphur dioxide, and other liquids in refrigeration and air conditioning systems. These valves can also be used to control water, oil, and air flow.

Standard applications of solenoid valves generally require that the valve be mounted directly in line in the piping with the inlet and outlet connections directly opposite each other. Simplified valve mounting is possible with the use of a bottom outlet which eliminates elbows and

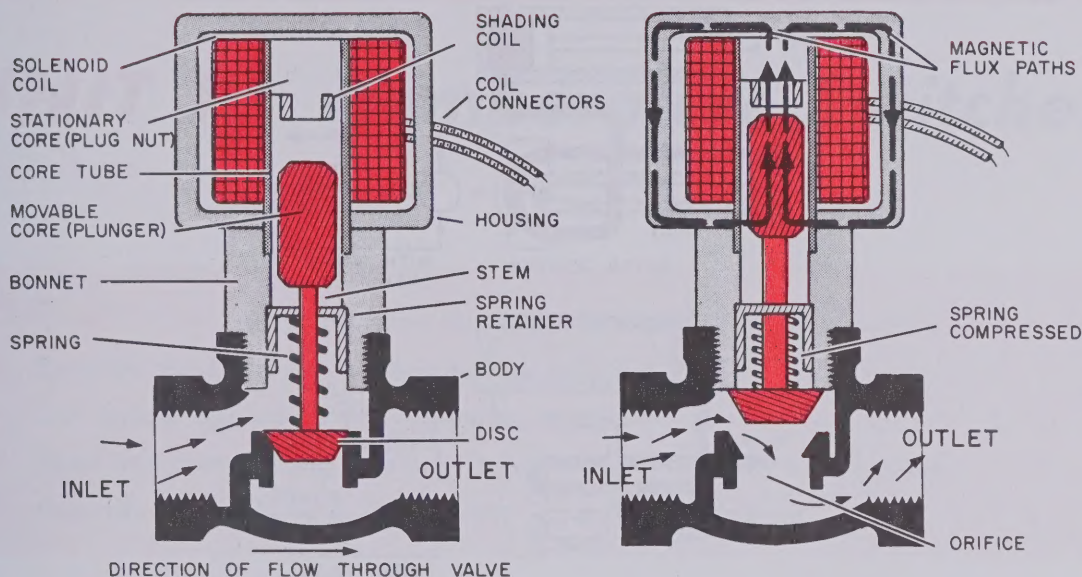


FIG. 14-1 Two-way solenoid valve (Courtesy Automatic Switch Co.)

bends. In the bottom outlet arrangement the normal side outlet is closed with a standard pipe plug.

The valve body is usually a special brass forging which is carefully checked and tested to insure that there will be no seepage due to porosities. The armature, or plunger, is made from a high grade stainless steel. The effects of residual magnetism are eliminated by the use of a kickoff pin and spring which prevent the armature from sticking. A shading coil insures that the armature will make a complete seal with the flat surface above it to eliminate noise and vibration.

It is possible to obtain dc coils with a special winding that will prevent the damage that normally results from an instantaneous voltage surge when the circuit is broken. Surge capacitors are not required with this type of coil.

To insure that the valve will always seat properly it is recommended that strainers be used to prevent grit or dirt from lodging in the orifice or valve seat. Dirt in these locations will cause leakage. The inlet and outlet connections

of the valve must not be reversed. The tightness of the valve depends to a degree on pressure acting downward on the sealing disc. This pressure is possible only when the inlet is connected to the proper point as indicated on the valve.

FOUR-WAY SOLENOID VALVES

Electrically operated, four-port, four-way air valves are used to control a double-acting cylinder, figure 14-2.

When the coil is de-energized, one side of the piston is at atmospheric pressure, and the other side is acted upon by the line pressure compressed air. When the valve magnet coil is energized, the valve exhausts the high pressure side of the piston to atmospheric pressure. As a result, the piston and its associated load reciprocate in response to the valve movement.

Four-way valves are used extensively in industry to control the operation of the pneumatic cylinders used on spot welders, press clutches, machine and assembly jig clamps, tools, and lifts.

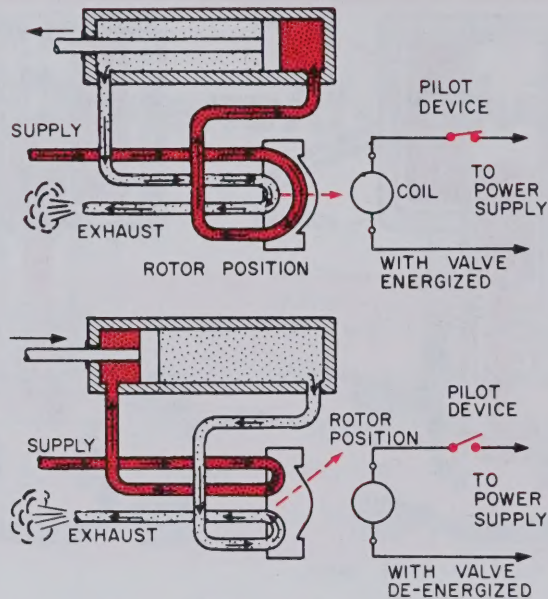


FIG. 14-2 Control of double-acting cylinder by a four-way, electrically operated valve shown with elementary diagrams.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Why is it important to understand the purpose and action of the total operational system when working with controls? *Maintenance*
2. If an electrically controlled, two-way solenoid valve is leaking, what is the probable cause? *Dirt*
3. What is the difference between a two-way solenoid valve and a flow switch?

Controls the flow

Detects the flow

UNIT 15 *Temperature Switches*

Objectives After studying this unit, the student will be able to:

- Describe the operation of temperature switches
- List several applications of temperature switches
- Read and draw wiring symbols and circuits for temperature switches
- Describe a solid-state control system

Temperature switches are designed to provide automatic control of temperature regulating equipment, figure 15-1. Industrial temperature controllers are used for applications where the temperature to be controlled is higher than the normal or ambient temperature. In general, the applications of temperature control are more concerned with the temperature regulation of liquids than of gases. This is a result of the relatively greater conductivity between the bulb and a liquid, as compared to the conductivity between the bulb and a gas (such as air). Thus, if air or gas temperatures are to be controlled, the sensitivity of the sensor decreases and the difference between the on and off points widens.

To operate a temperature switch, the gas vapor or liquid pressure expands a metal bellows against the force of a spring. The expanding bellows moves an operating pin. The pin snaps a precision switch to its operating position when a preset point is reached. (This action is similar to the operation of industrial pressure switches.) The pressure which operates the switch is proportional to the temperature of a liquid in a closed bulb. The precision switch snaps back to its normal position when the pressure in the

bellows drops enough to allow the main spring to compress the bellows.

There are many types of thermostats which can be used to provide automatic control of space heating and cooling equipment. A typical thermostat is a temperature actuated, two-wire (or more) control pilot device (switch). Temperature-actuated switches are used to control circuits in order to operate heaters, blowers, fans, solenoid valves, pumps, and other devices. Figure 15-2 illustrates a two-wire temperature switch controlling a cooling fan motor. When a high temperature closes the temperature switch, it energizes coil F. Coil F closes F contacts starting the motor.

SOLID-STATE TEMPERATURE CONTROL SYSTEMS

There are many different types of temperature switches, both mechanical and electronic. Figure 15-3 shows a panel mounting, solid-state temperature control system. This system is designed with three high-accuracy thermistor temperature sensors. These sensors can be used to protect

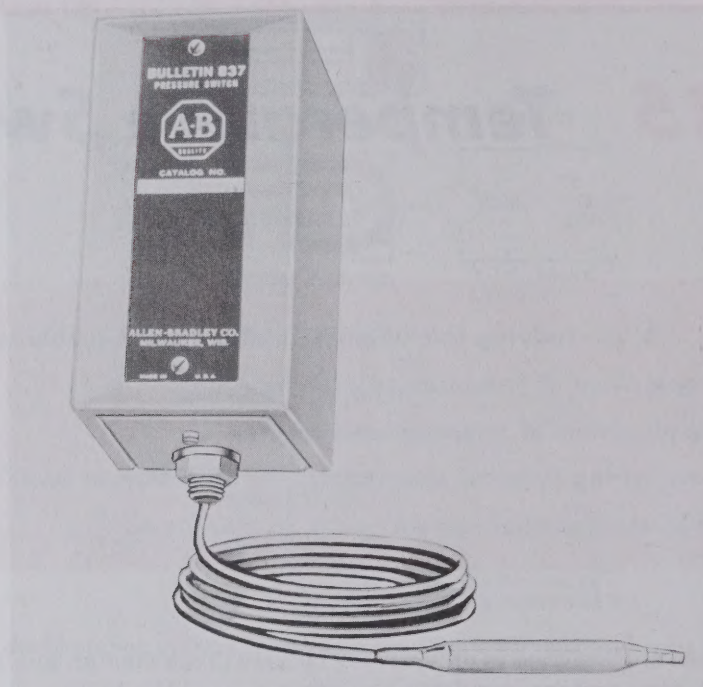


FIG. 15-1 Industrial temperature switch with extension bulb (Courtesy Allen-Bradley Co.)

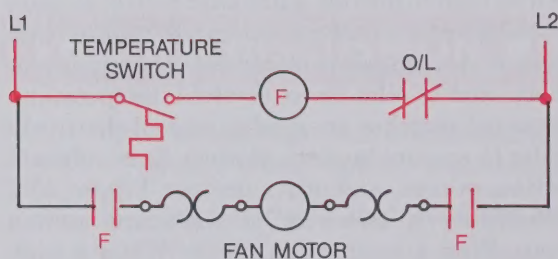


FIG. 15-2 Temperature switch controlling a cooling fan

three-phase transformer coils from overheating. The sensors transmit the internal coil temperatures to a microprocessor (minicomputer) which is programmed to provide a digital display in



FIG. 15-3 Solid-state temperature control system using thermistor-type temperature sensors (Courtesy of Square D Co.)

degrees on the front panel of the control module. Electrical hookup terminals are provided on the back for alarms and to energize fan motors.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What are some applications of temperature-actuated switches?

2. How is the average electrician involved with electronic temperature controls?

*Activate Motor Controls - Protect Transformers
To wire these switches in control circuits*

SECTION FOUR

A series of ten thin, horizontal white lines stacked vertically, spanning the width of the page.

BASIC CONTROL CIRCUITS

- UNIT 16** Two-wire Controls
- UNIT 17** Three-wire and Separate Controls
- UNIT 18** Hand-off Automatic Controls
- UNIT 19** Multiple Push-button Stations
- UNIT 20** Interlocking Methods for Reversing Control
- UNIT 21** Sequence Control
- UNIT 22** Time-delay, Low-voltage Release Relay

UNIT 16 Two-wire Controls

Objectives After studying this unit, the student will be able to:

- List the advantages of two-wire control
- Connect two-wire devices to motor starters
- Read and draw simple diagrams for two-wire control

A two-wire control may be a toggle switch, pressure switch, float switch, limit switch, thermostat, or any other type of switch having definite *on* and *off* positions. As indicated in Unit 15, devices of this type generally are designed to handle small currents. Two-wire control devices will not carry sufficient current to operate large motors. In addition, 230-volt motors and three-phase motors require more contacts than the one contact usually provided on two-wire devices.

Two-wire controls may be connected to operating coils of magnetic switches, as shown in figure 16-1. When the switch is closed, the control circuit is completed through the coil (M). When the coil is energized, it closes the contacts at M and runs the motor. When the switch is opened, the coil is de-energized and the contacts open to stop the motor. In the case of an overload, the thermal heaters open the overload contacts in the control circuit and de-energize the coil, thus stopping the motor. Two-wire control provides no voltage (or low voltage) release. When the starter is wired, as shown in figure 16-1, it will operate automatically in response to the control device. A human operator is not required. The control maintaining contact 2-3 (shown in the wiring diagram) is

furnished with the starter. However, this contact is not used in two-wire control. For simplicity, this contact is omitted from the two-wire elementary diagram. The motor starter in figure 16-1 is a line voltage, or across-the-line, starter (described in Unit 3).

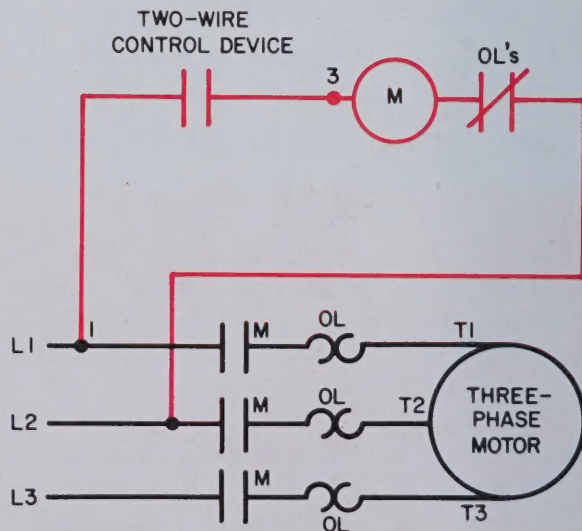


FIG. 16-1(A) Basic two-wire control circuit—elementary diagram

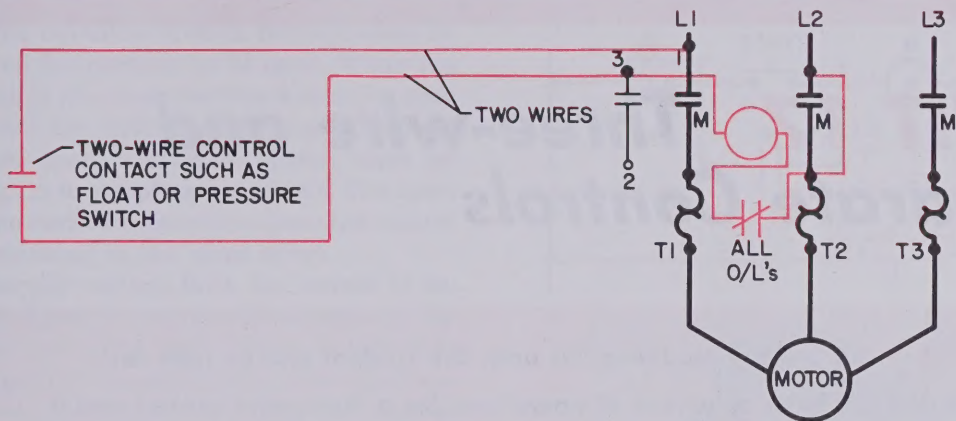
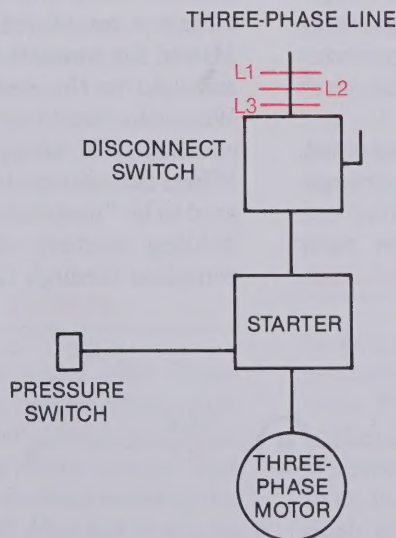


FIG. 16-1(B) Basic two-wire control circuit—wiring diagram

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What are some advantages to the use of two-wire control?
2. How many wires are required for a two-wire control device?
3. In the conduit diagram shown, determine how many wires are in each conduit between each piece of equipment. Identify each wire terminal connection and the quantity of wires, as shown in the example above the disconnect switch.



4. Draw an elementary diagram of a pressure switch controlling a motor starter only.

UNIT 17 Three-wire and Separate Controls

Objectives After studying this unit, the student will be able to:

- Describe the basic sequence of operations for a three-wire control circuit
- Describe the basic sequence of operations for a separate control circuit
- List the advantages of each type of circuit
- Connect three-wire and separate control circuits
- Connect pilot indicating lights
- Connect an alarm silencing circuit
- Read and draw three-wire and separate control circuits

THREE-WIRE CONTROLS

A three-wire control circuit uses momentary contact, start-stop stations, and a holding circuit interlock connected in parallel with the start button, to maintain the circuit.

In general, three-wire devices are connected, as shown in figure 17-1. Although the arrangement of the various parts may vary from one manufacturer's switch to another, the basic circuit remains the same.

The sequence of operation for this circuit is as follows: when the start button is pushed, the circuit is completed through the coil (shown as M) and the contacts at M close. The power circuit contacts to the motor also close (not shown). When the start button is released, the holding contact at M keeps this auxiliary contact on. When the starter is used in this manner, it is said to be "maintaining" or "sealing." With the holding contact closed, the circuit is still complete through the coil. If the stop button is

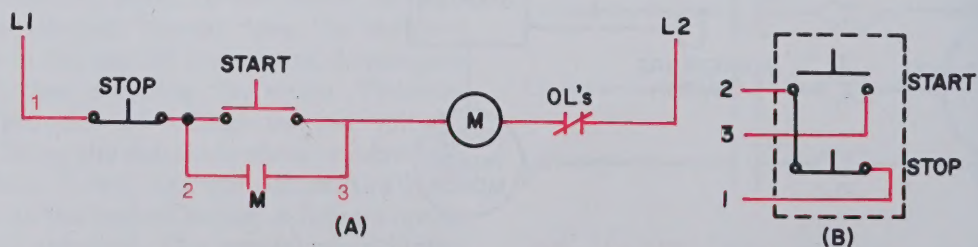


FIG. 17-1 Basic three-wire control circuit

pushed, the circuit is broken, the coil loses its energy, and the contacts at M open. When the stop button is released, the circuit remains open because both the holding contact and the start button are open. The start button must be pushed again to complete the circuit. The operation of the overload protection opens the control circuit, resulting in the same effect.

If the supply voltage fails, the circuit is de-energized. When the supply voltage returns, the circuit remains open until the start button is pushed again. This arrangement is called *no-voltage protection* and protects both the operator and the equipment.

The pushbutton station wiring diagram (B of figure 17-1) represents the physical station. It shows the relative positions of the units, the internal wiring, and the connections to the starter. The wires to the terminals are labeled 1, 2, and 3 (giving rise to the name “three-wire control”). For similar diagrams, review figures 14-2 and 15-2. A pilot light or alarm can be added to this circuit to indicate when the motor is not running (figure 14-2). Normally closed auxiliary contacts are used to switch the pilot light on and off. When the motor is running, these contacts are open; when the motor is stopped, the contacts are closed and the pilot light is on. A pilot light may be installed to indicate when the motor is running. For this case, the pilot light is connected between control terminal 3 and line 2. Except for this modification, the circuit is a basic three-wire, push-button control circuit.

PUSH-TO-TEST PILOT LIGHTS

It is necessary to restart a motor after it has been stopped by a three-wire control circuit with *low voltage protection*. An indicating lamp often is used to signal this when a motor stops so that it can be restarted after the problem causing the stoppage is cleared. Because pilot lights are an important component in such cases, they are tested frequently to insure operation. Push-to-

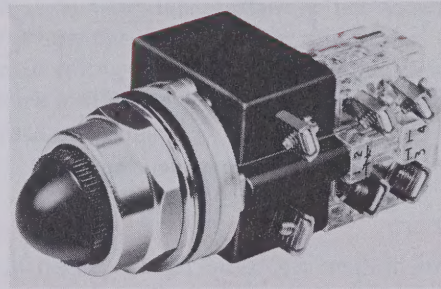
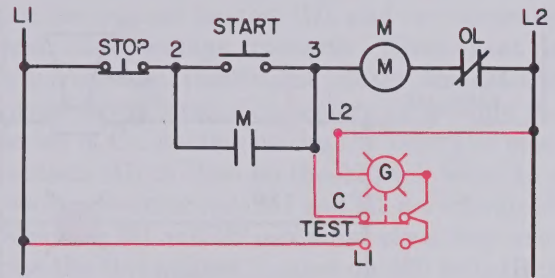


FIG. 17-2 Push-to-test oil-tight push button (Courtesy Square D Co.)

test pilot lights show immediately if a circuit is off or if the lamp is burned out. Part of figure 17-2 shows the schematic wiring for such a circuit. The three-wire motor starter control circuit is wired as usual. Note that the pilot lamp is energized from terminal 3 down to C, through a normally closed push button to L2. To test, the lamp is pushed, opening the circuit at C and closing it across L1. With a push-button arrangement, the lamp is tested directly across lines 1 and 2.

ALARM SILENCING CIRCUIT

Sirens, horns, and loud buzzers are also used in production systems to call attention to malfunctions. The problem is acknowledged by attempts to silence this “noise pollution.” A typical circuit is shown in figure 17-3. Assume a high pressure in an industrial system is dangerous to continue. Such a condition will close a pressure switch. When this switch closes, the alarm is sounded through normally closed contact S. In addition,

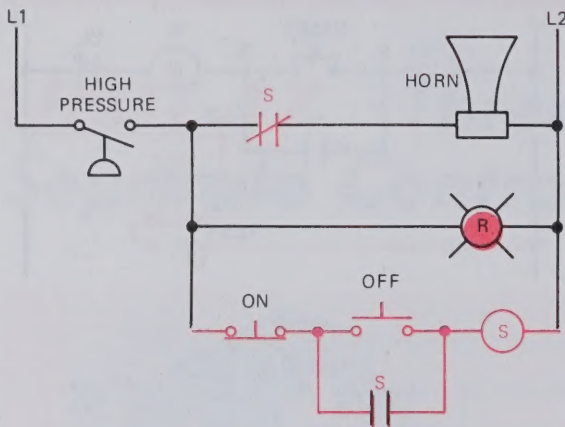


FIG. 17-3 Alarm silencing circuit

the red indicating lamp lights. When alerted, maintenance personnel can silence the alarm by depressing the *off* push button. The red light continues to silently announce the problem until it is cleared. After the pressure switch opens, the alarm system can be reactivated by pressing the *on* button. There are virtually unlimited control circuits using the three-wire system.

SEPARATE CONTROL

It is sometimes desirable to operate push buttons or other control devices at some voltage lower than the motor voltage. In the control system for such a case, a separate source — such as an isolating transformer or an independent voltage supply — provides the power to the control circuit. This independent voltage is separate from the main power supply for the motor.

One form of separate control is shown in figure 17-4. This is an elementary diagram of a cooling circuit for a commercial air-conditioning installation. When the thermostat calls for cooling, the compressor motor starter coil (shown as M) is energized through the stepdown isolating transformer. When coil M is energized, power contacts in the 240-volt circuit close to start the refrigeration compressor motor. Since the control

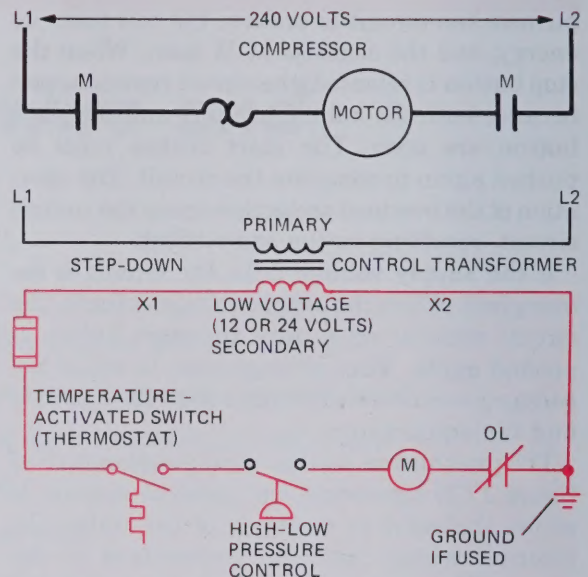


FIG. 17-4 Separate control used in air conditioning cooling circuit

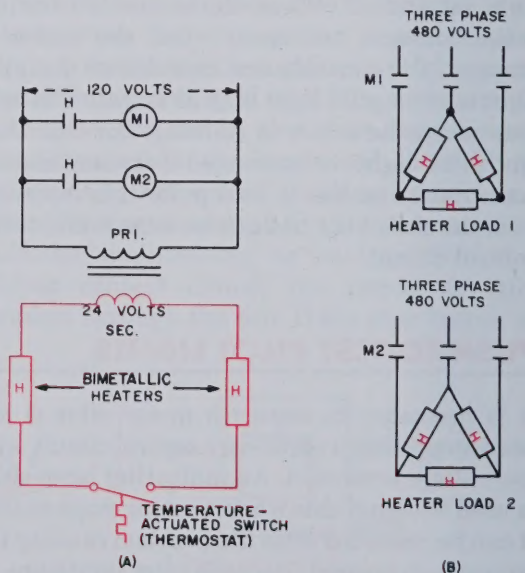


FIG. 17-5 Separate control used in air conditioning heating circuit

circuit is separated from the power circuit by the isolating control transformer, there is no electrical connection between the two circuits. For this reason, the wire jumper attached to L2 on a starter should be removed for different voltages. However, the overload relay control contact must be included in the separate control wiring. The maintenance technician must also insure that the control transformer voltages match the voltages used and that the proper connections are made.

Another example of separate control is the thermal relay shown in figure 17-5. This control consists of a line to a low-voltage transformer,

two low-voltage heaters (H), and two normally open line voltage contacts. When heat is required, the thermostat closes the 24-volt circuit to the bimetallic heaters. In seconds, the action of the heaters causes the normally open contacts (H) to close on the 120-volt side. As a result, contactor coils M1 and M2 are energized. When the M1 and M2 contactors close, they energize the three-phase heaters on 480 volts (B in figure 17-5). Circulating blowers (not shown) will start when the heaters are energized. Three separate voltages are shown in figure 17-5. Both two-wire and three-wire controls are used with separate controls.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Draw a control circuit with no-voltage protection. Describe how this method of wiring protects the machine operator.
2. In the conduit layout shown in figure 17-6, determine how many wires are contained in each conduit between each piece of equipment. Identify each wire with a proper terminal marking as shown in the line above the disconnect switch.

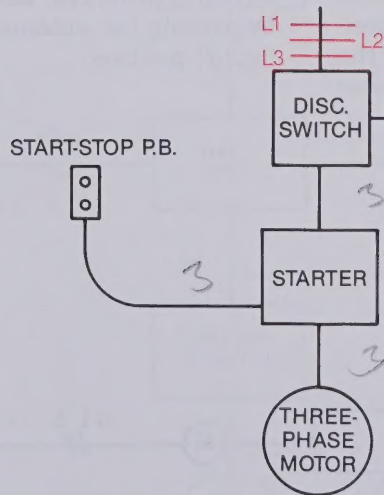


FIG. 17-6

UNIT 18 Hand-off Automatic Controls

Objectives After studying this unit, the student will be able to:

- State the purpose of hand-off-automatic controls
- Connect hand-off-automatic controls
- Read and draw diagrams using hand-off-automatic control

Hand-off-automatic switches are used to select the function of a motor controller either manually or automatically. This selector switch may be a separate unit or built into the starter enclosure cover. A typical control circuit using a single-break selector switch is shown in figure 18-1.

With the switch turned to the HAND (manual) position, coil (M) is energized all the time and the motor runs continuously. In the OFF position, the motor does not run at all. In the AUTOMATIC position, the motor runs whenever

the two-wire control device is closed. An operator does not need to be present. The control device may be a pressure switch, limit switch, thermostat, or other two-wire control pilot device.

The heavy-duty, three-position double-break selector switch shown in figure 18-2 is also used for manual and automatic control. When the switch is turned to "hand," the coil is energized, by-passing the automatic control device in the "auto" position.

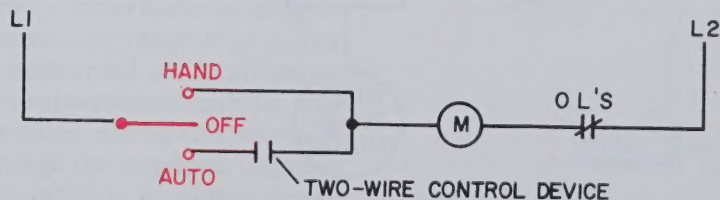


FIG. 18-1 Standard duty, three-position selector switch in control circuit

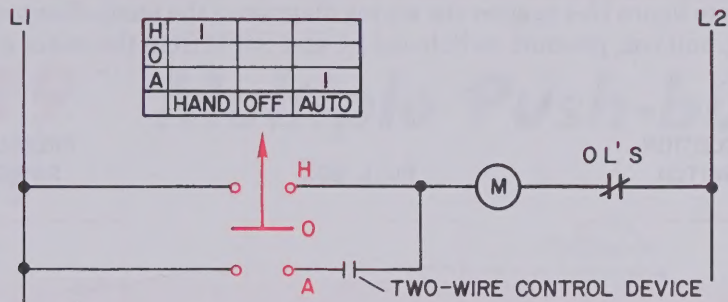


FIG. 18-2 Diagram of a heavy duty, three-position selector switch in control circuit

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. A selector switch and two-wire pilot device can not be used to control a large motor directly, but rather must be connected to a magnetic starter. Explain why this is true.
2. Determine the minimum number of wires in each conduit shown in figure 18-3.

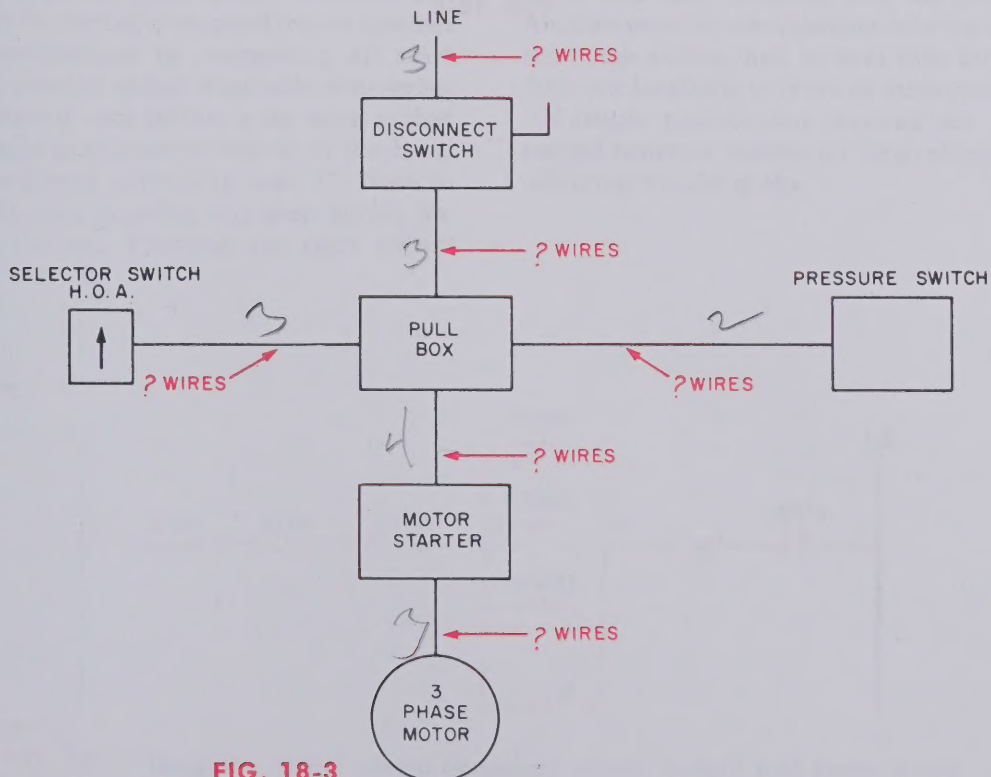


FIG. 18-3

3. Complete figure 18-4 to show the wiring diagram of the hand-off-automatic selector switch, pull box, pressure switch and L1 and coil M from the motor starter control circuit.

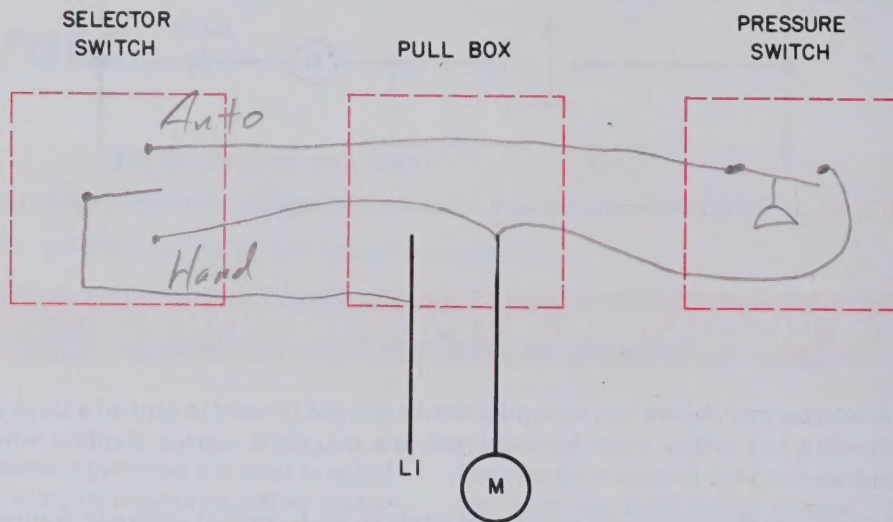


FIG. 18-4

UNIT 19 Multiple Push-button Stations

Objectives After studying this unit, the student will be able to:

- Read and interpret diagrams using multiple push-button stations
- Draw diagrams using multiple push-button stations
- Connect multiple push-button stations

The conventional three-wire, push-button control circuit may be extended by the addition of one or more push-button control stations. The motor may be started or stopped from a number of separate stations by connecting all start buttons in parallel and all stop buttons in series. The operation of each station is the same as that of the single push-button control in the basic three-wire circuit covered in unit 17. Note in figure 19-1 that pressing any stop button de-energizes the coil. Pressing any start button energizes the coil.

When a motor must be started and stopped from more than one location, any number of start and stop buttons may be connected. Another possible arrangement is to use only one start-stop station and several stop buttons at different locations to serve as emergency stops.

Multiple push-button stations are used to control conveyor motors on large shipping and receiving freight docks.

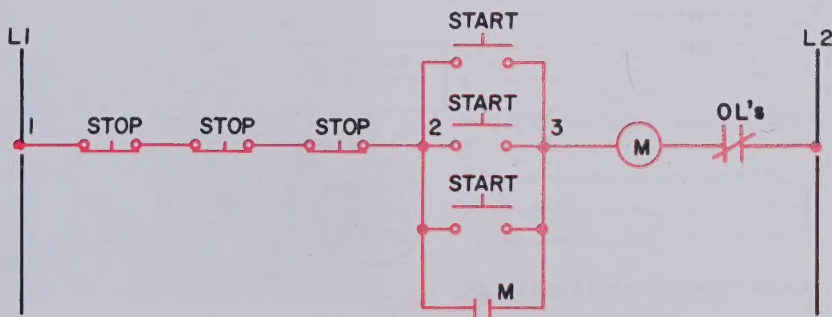


FIG. 19-1 Three-wire control using a momentary contact, multiple push button station

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Using the line diagram in figure 19-2, determine the number of wires controlling the three-phase motor. The conduit layout plan indicates the sections of conduit for which the quantity of wires is to be determined.
2. Referring to figure 19-2, select the minimum size conduit for each run. Use the appropriate locally enforced electrical code — national, state, county, or city.

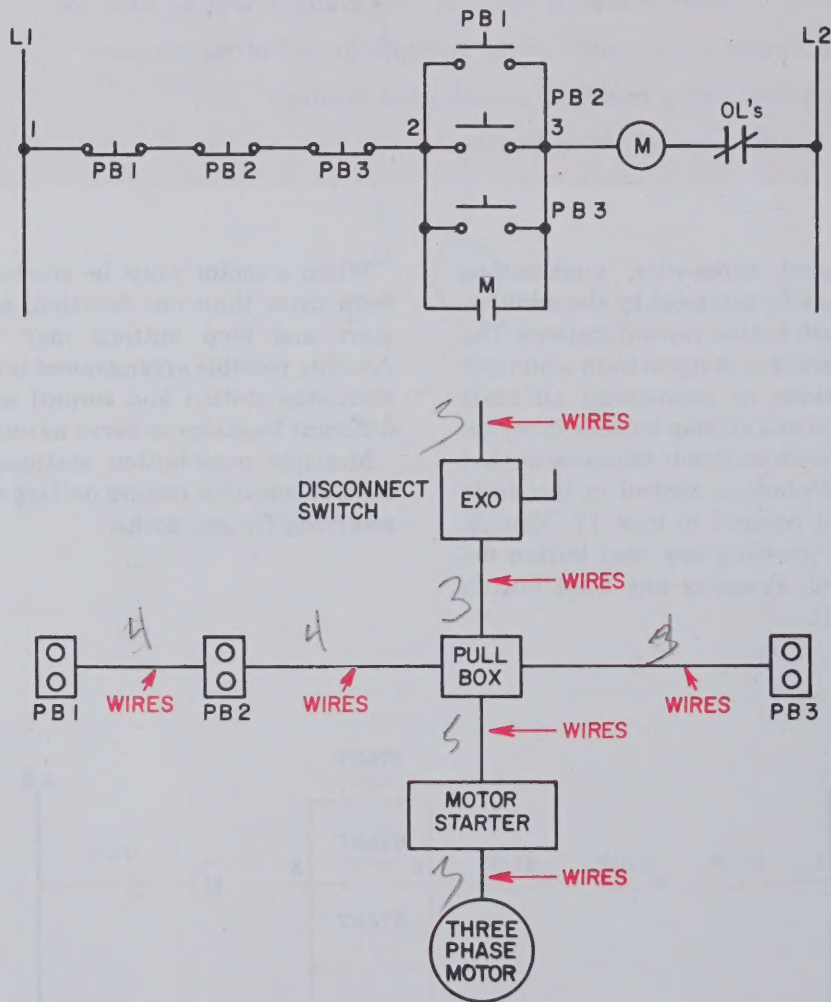


FIG. 19-2

UNIT 20 Interlocking Methods for Reversing Control

Objectives After studying this unit, the student will be able to:

- Explain the purpose of the various interlocking methods
- Read and interpret wiring and line diagrams of reversing controls
- Read and interpret wiring and line diagrams of interlocking controls
- Wire and troubleshoot reversing and interlocking controls

The direction of rotation of three-phase motors can be reversed by interchanging any two motor leads to the line. If magnetic control devices are to be used, then reversing starters accomplish the reversal of the motor direction, figure 20-1A.

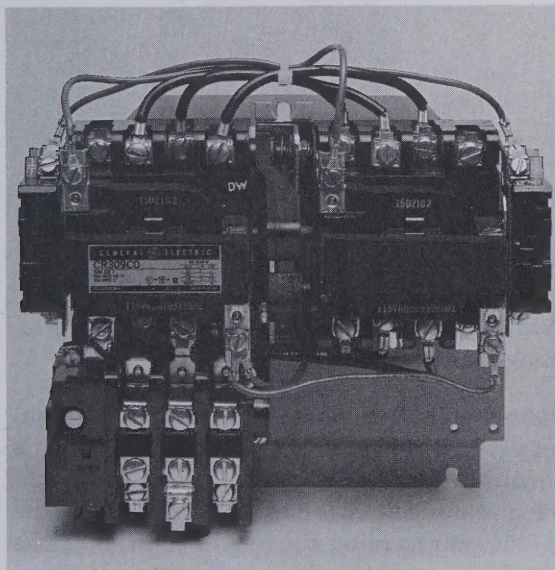


FIG. 20-1(A) Reversing starter (Courtesy General Electric Company)

Reversing starters wired to NEMA standards interchange lines L1 and L3, figure 20-1B. To do this, two contactors for the starter assembly are required — one for the forward direction and one for the reverse direction, figure 20-1C. A technique called *interlocking* is used to prevent the contactors from being energized simultaneously or closing together and causing a short circuit. There are three basic methods of interlocking.

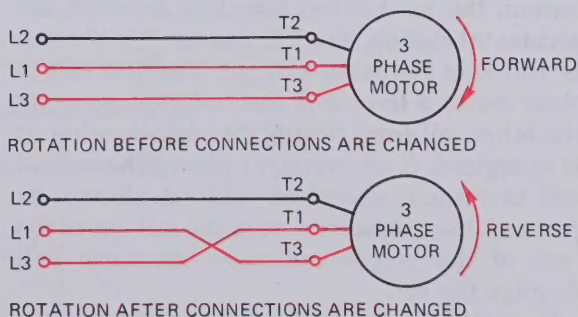


FIG. 20-1(B) Reversing rotation of an induction motor

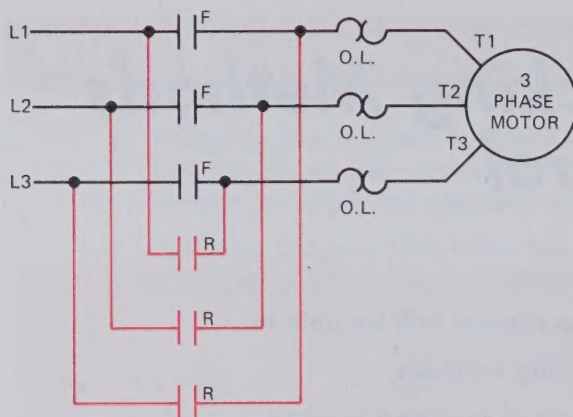


FIG. 20-1(C) Elementary diagram of a reversing starter power circuit

MECHANICAL INTERLOCK

A mechanical interlocking device is assembled at the factory between the forward and reverse contactors. This interlock locks out one contactor at the beginning of the stroke of either contactor to prevent short circuits and burnouts.

The mechanical interlock between the contactors is represented in the elementary diagram of figure 20-2 by the broken line between the coils. The broken line indicates that coils F and R cannot close contacts simultaneously because of the mechanical interlocking action of the device.

When the forward contactor coil (F) is energized and closed through the forward push button, the mechanical interlock prevents the accidental closing of coil R. Starter F is blocked by coil R in the same manner. The first coil to close moves a lever to a position that prevents the other coil from closing its contacts when it is energized. If an oversight allows the second coil to remain energized without closing its contacts, the excess current in the coil due to the lack of the proper inductive reactance will damage the coil.

Note in the elementary diagram of figure 20-2 that the stop button must be pushed before the motor can be reversed.

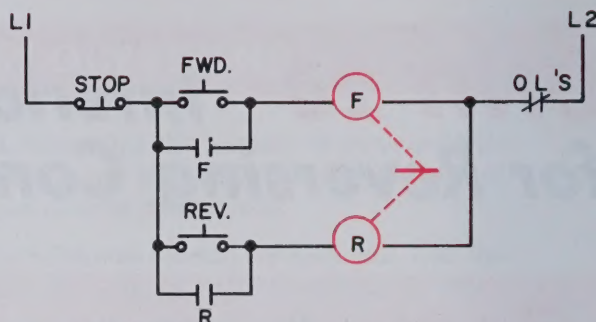


FIG. 20-2 Mechanical interlock between the coils prevents the starter from closing all contacts simultaneously. Only one contactor can close at a time.

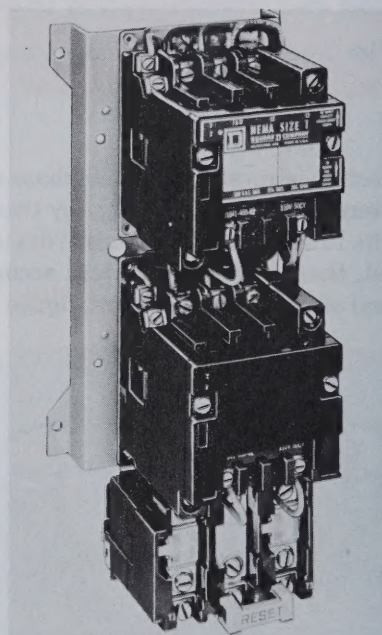


FIG. 20-3(A) Vertical reversing motor starter (Courtesy Square D Co.)

Reversing starters are available in horizontal and vertical construction. A vertical starter is shown in figure 20-3A.

A mechanical interlock is installed on the majority of reversing starters in addition to the use of one or both of the following electrical methods: push-button interlock and auxiliary contact interlock.

PUSH-BUTTON INTERLOCK

Push-button interlocking is an *electrical method* of preventing both starter coils from being energized simultaneously.

When the forward button in figure 20-3B is pressed, coil F is energized and the normally open (NO) contact F closes to hold in the forward contactor. Because the normally closed (NC) contacts are used in the forward and reverse push-button units, there is no need to press the stop button before changing the direction of rotation. If the reverse button is pressed while the motor is running in the forward direction, the forward control circuit is de-energized and the reverse contactor is energized and held closed.

Repeated reversals of the direction of motor rotation are not recommended. Such reversals may cause the overload relays and starting fuses to overheat; this disconnects the motor from the circuit. The driven machine may be damaged also. It may be necessary to wait until the motor has coasted to a standstill.

NEMA specifications call for a starter to be derated. That is, the next size larger starter

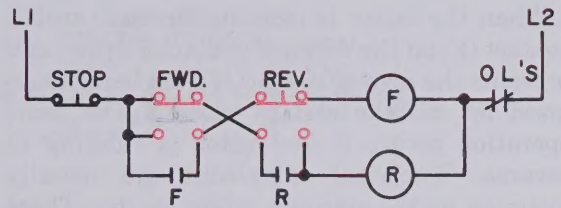


FIG. 20-3(B) Double-circuit push buttons are used for push button interlocking

must be selected when it is to be used for “plug-
ging” to stop, or “reversing” at a rate of more
than five times per minute.

Reversing starters consisting of mechanical and electrical interlocked devices are preferred for maximum safety.

AUXILIARY CONTACT INTERLOCK

Another method of electrical interlock consists of normally closed auxiliary contacts on the forward and reverse contactors of a reversing starter, figure 20-4.

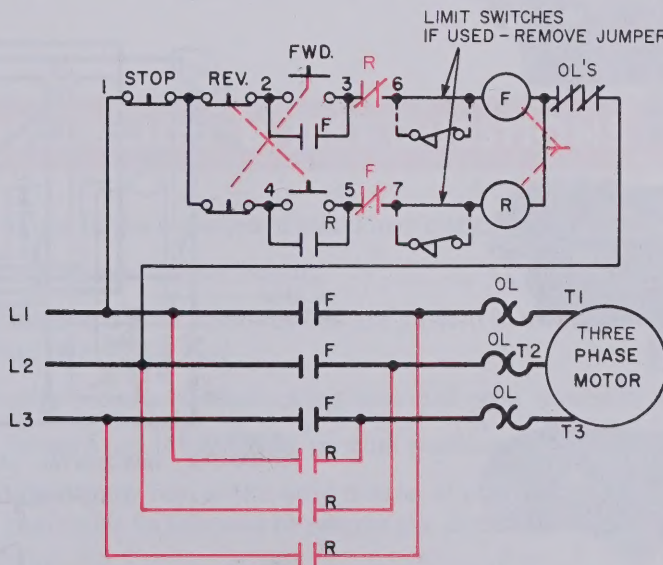


FIG. 20-4 Elementary diagram of the reversing starter shown in figure 20-1(A). The mechanical, push button and auxiliary contact interlocks are indicated.

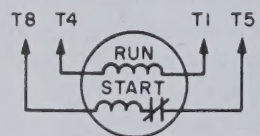
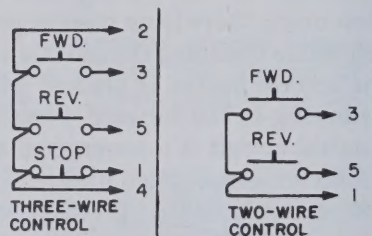
When the motor is running forward, an NC contact (F) on the forward contactor opens and prevents the reverse contactor from being energized by mistake and by closing. The same operation occurs if the motor is running in reverse. Electrical interlocks are usually mounted on the side of a motor starter. These are shown in figure 20-5.

The term, *interlocking*, is also used generally when referring to motor controllers and control stations that are interconnected to provide control of production operations.

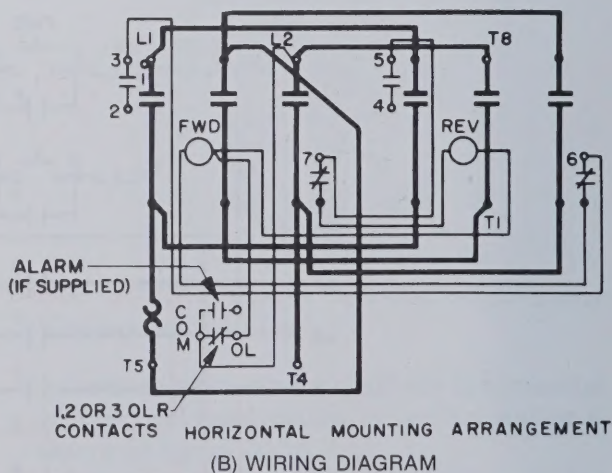


FIG. 20-5 Electrical interlocks and terminal blocks (Courtesy of EATON Corp., Cutler-Hammer Products)

To reverse the direction of rotation of single-phase motors, *either* the starting or running winding motor leads are interchanged, but not both. Figure 20-6A completes the wiring diagram for the single-phase, four-wire, split phase induction or capacitor motor; figure 20-6B is a wiring diagram for a single-phase horizontal starter; and figure 20-6C is a line diagram of the connections.



(A) CAPACITOR OR SPLIT PHASE MOTOR



(B) WIRING DIAGRAM

FIG. 20-6 Sizes 00, 0, and 1, three-pole reversing starters used with single-phase, four-lead capacitor or split phase motors

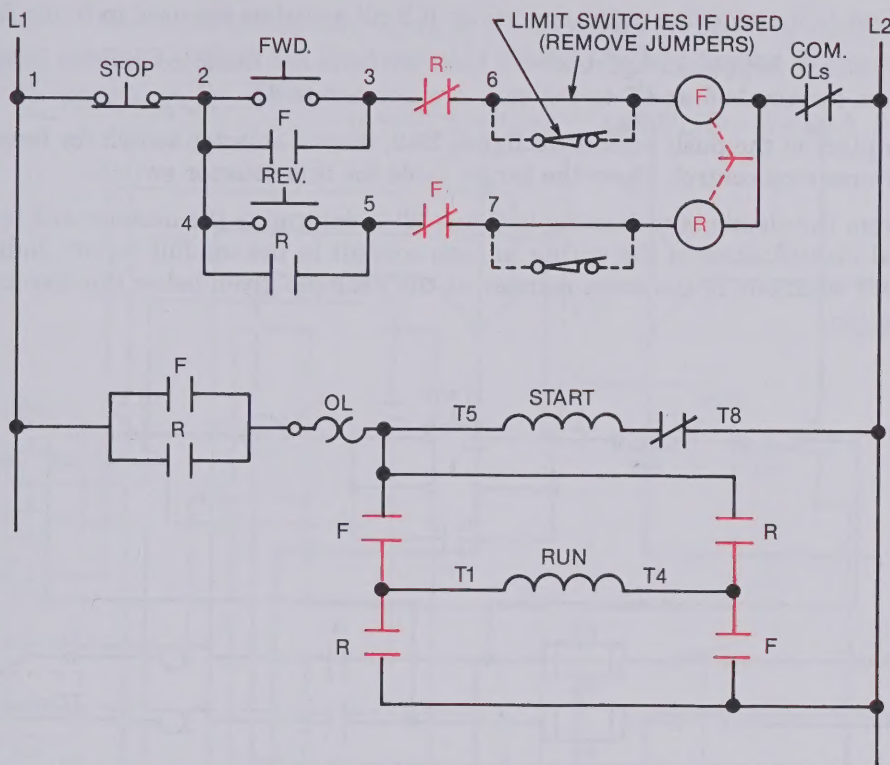


FIG. 20-6(C) Elementary diagram for figures 20-6(A) & (B)

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. How is a change in the direction of rotation of a three-phase motor accomplished? *Switch L1 & L3*
2. What is the purpose of interlocking? *Prevents both starters engaging*
3. What will happen if both start buttons are pushed in a control with push-button interlocking? Why? *Nothing*
4. How is auxiliary contact interlocking obtained on a reversing starter? *NC coil contacts placed in opposite circuits*
5. When the forward coil is energized, in what position is the forward interlock (F)?
6. If a mechanical interlock is the only means of interlocking used, describe the operation that must be followed to reverse the direction of rotation of the motor while running. *Stop must be pushed*
7. If pilot lights are to indicate the direction of rotation of a motor, where should the devices be connected so as not to add any contacts?

in parallel with the coils

8. What is the sequence of the operations if limit switches are used in figure 20-4?
9. What will happen in figure 20-4 if limit switches are installed and the jumpers from terminals 6 and 7 to the coils are not removed? *Limit Switch will not work*
10. In place of the push buttons in figure 20-2, draw a selector switch for forward-reverse-stop control. Show the target table for this selector switch.
11. From the elementary drawing in figure 20-7, determine the number and terminal identification of the wiring in each conduit in the conduit layout. Indicate your solutions in the same manner as the example given below the disconnect switch.

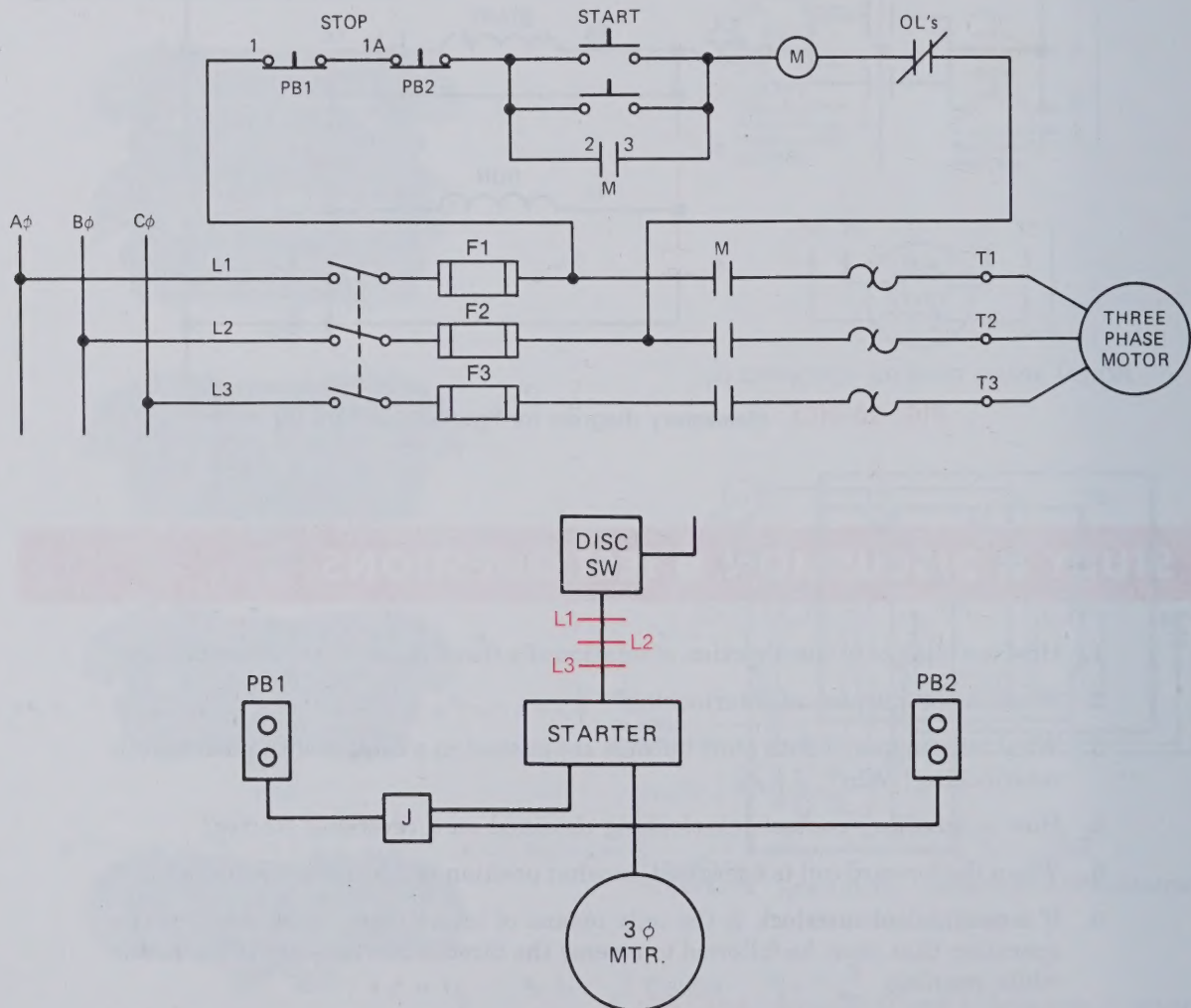


FIG. 20-7

12. Convert the control circuit only, figure 20-8, from the wiring diagram to an elementary diagram. Include the limit switches (RLS, FLS) as operating in the control circuit.

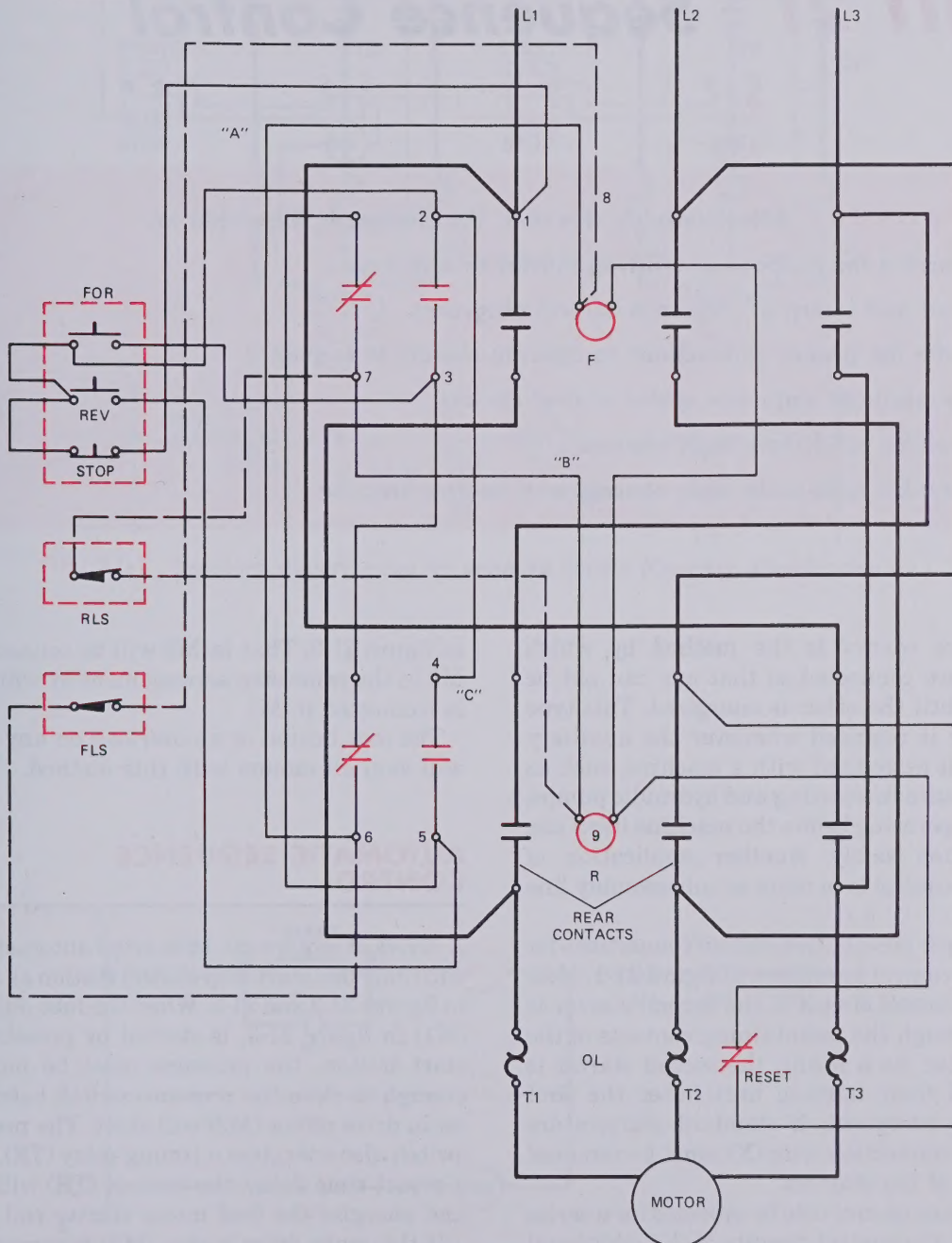


FIG. 20-8

UNIT 21 Sequence Control

Objectives After studying this unit, the student will be able to:

- Describe the purpose of starting motors in sequence
- Read and interpret sequence control diagrams
- Make the proper connections to operate motors in sequence
- Troubleshoot sequence motor control circuits
- Describe solid-state logic elements
- Describe solid-state logic concept and control function

Sequence control is the method by which starters are connected so that one can not be started until the other is energized. This type of control is required whenever the auxiliary equipment associated with a machine, such as high-pressure lubricating and hydraulic pumps, must be operating before the machine itself can be operated safely. Another application of sequence control is in main or subassembly line conveyors.

The proper push-button station connections for sequence control are shown in figure 21-1. Note that the control circuit of the second starter is wired through the maintaining contacts of the first starter. As a result, the second starter is prevented from starting until after the first starter is energized. If standard starters are used, the connection wire (X) must be removed from one of the starters.

If sequence control is to be provided for a series of motors, the control circuits of the additional starters can be connected in the manner shown

in figure 21-2. That is, M3 will be connected to M2 in the same step arrangement by which M2 is connected to M1.

The stop button or an overload on any motor will stop all motors with this method.

AUTOMATIC SEQUENCE CONTROL

A series of motors can be started automatically with only one start-stop control station as shown in figures 21-2 and 21-3. When the lube oil pump, (M1) in figure 21-3, is started by pressing the start button, the pressure must be built up enough to close the pressure switch before the main drive motor (M2) will start. The pressure switch also energizes a timing relay (TR). After a preset time delay, the contact (TR) will close and energize the feed motor starter coil (M3).

If the main drive motor (M2) becomes overloaded, the starter and timing relay (TR) will

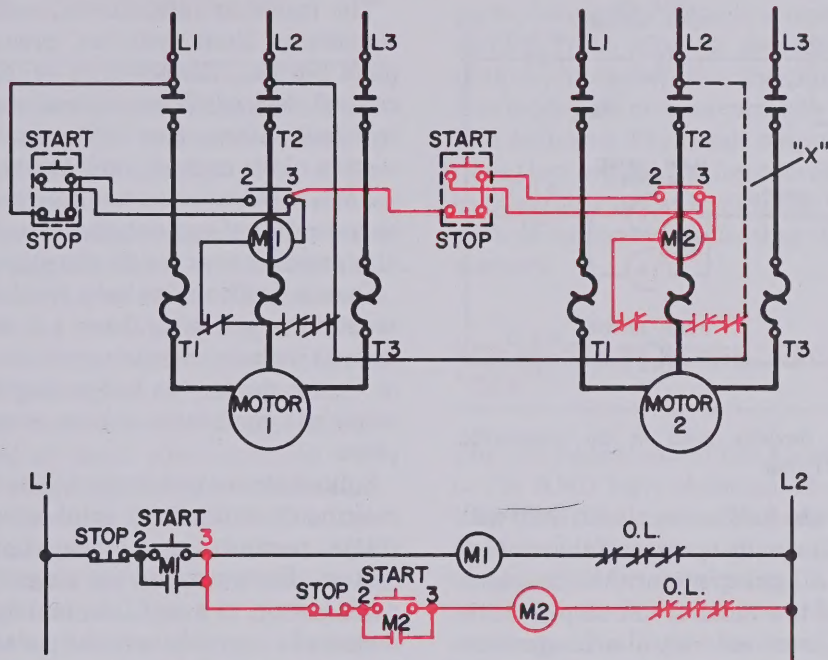


FIG. 21-1 Standard starters wired for sequence control (Courtesy Allen-Bradley Co.)

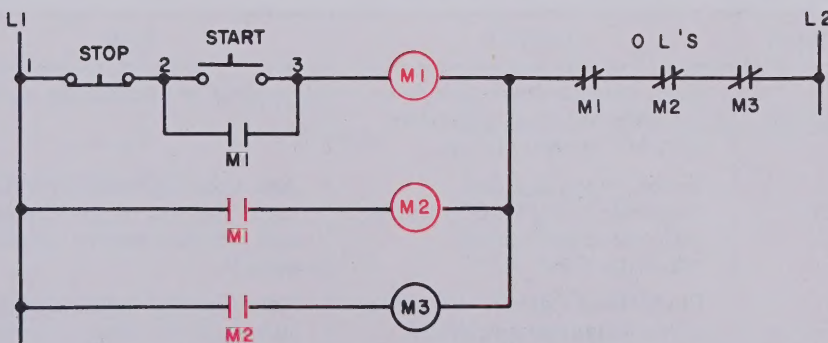


FIG. 21-2 Auxiliary contacts (or interlocks) used for automatic sequence control. Contact (M1) energizes coil (M2); contact (M2) energizes coil (M3)

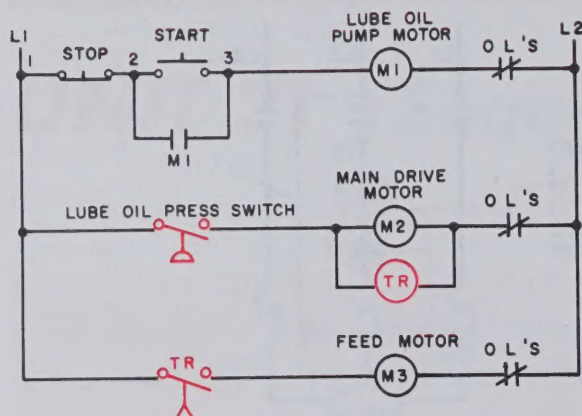


FIG. 21-3 Pilot devices used in an automatic sequence control scheme

open. As a result, the feed motor circuit (M3) will be de-energized due to the opening of the contact (TR). If the lube oil pump motor (M1) becomes overloaded, all of the motors will stop. Practically any desired overload control arrangement is possible.

LOGIC CONCEPT AND CONTROL FUNCTION

The functions of electrical control systems and their associated devices can be grouped into three functions: *input*, *logic*, *output*. Table 21-1 shows the function, devices and their use.

The *input*, or information, section of control consists of limit switches, pressure switches, push buttons, temperature sensors, and other control devices. These accessories receive and transmit information to the *logic*, or decision, section of the control, such as a relay or transistor. When information has been received, it must be assimilated and correlated in order to arrive at a decision to act or do something, the *output*.

Once a decision has been reached, the control must take action or have an output. Typical actions include energizing a solenoid, contactor or motor starter, an indicating light, or other electrical apparatus where something takes place.

Solid-state control performs the same decision-making function in a solid-state system that relays perform in a conventional magnetic system. Relays convert a single input from a push button to a coil into multiple outputs by means of a movable armature closing and opening contacts. Solid-state control logic elements convert a single input, or combination of inputs, into a single output by controlling a transistor.

The development of solid-state control has introduced new concepts and terminology to the electrical industry. This is true even though solid-state control functionally duplicates conventional magnetic control devices. It is in the area of performing the logic function that solid-state control is applied.

TABLE 21-1 Functions and Their Associated Devices

FUNCTION	DEVICE	USE
Input (Information)	Push buttons, limit switches, pressure switches, proximity switches, photocells, etc.	Sensing or information source
Logic (Decision)	Relays, electron tubes, magnetic amplifiers, hydraulic and pneumatic valves, transistors, etc.	Acts upon information from input devices; makes decisions and provides desired output signals.
Output (Action)	Contactors, starters, solenoids, power magnetic amplifiers, electronic and solid-state contactors.	Amplifies the logic output signals to the desired power level.

SOLID-STATE LOGIC ELEMENT "AND"

Combining several transistors with needed resistors, inductors, etc., into one sealed unit, or component, yields a logic element. Many different internal arrangements are manufactured to obtain nearly any logical sequence of events. Figure 21-4 graphically shows an element that requires three signals, or inputs. This element is compared with the notation for magnetic relay contacts in series. All contacts must be closed to obtain an output signal or current flow.

The AND logic element is a solid-state module that can be used by itself, when provided with the necessary voltage signals, to perform a similar function as shown in figure 21-3. The logic symbol shown in figure 21-4 is called an "AND." A and B and C must be energized to have an output to control further. Figure 21-5 compares electromagnetic and solid-state logic symbols.

Transistorized solid-state control is a way of controlling machines and processes electronically using such logic elements and accessories. They are not subject to wear or environmental effects. Logic elements accomplish the same decision making function as relays in conventional control systems, but they do not have moving

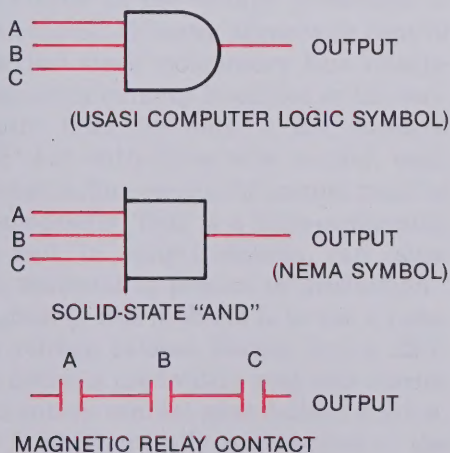


FIG. 21-4 Solid-state diagram symbols compared with magnetic relay contact symbols. A and B and C must have a proper signal applied to obtain an output.

parts. Solid-state controls accept electrical input signals from sensing devices such as push buttons, limit switches, and proximity switches. The solid-state devices correlate this information into decisions. Electronic output amplifier functions then convert the logic-level decision signals to the proper power level which operates devices such as solenoids, indicating lights, and motor starters.

SOLID-STATE LOGIC ELEMENT "OR"

The OR logic element has three inputs (similar to the AND logic element). However, this unit may have an output with a signal applied to A or B or C, as shown in figure 21-5. This is not an example of sequencing. A comparison of symbols is shown to help avoid confusing these elements. The logic element OR is similar to being controlled by start buttons connected in parallel, in multiple push-button stations.

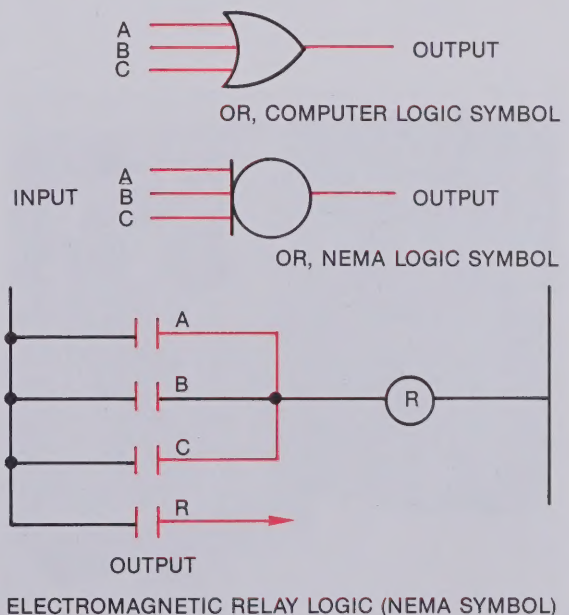


FIG. 21-5 Comparing electromagnetic relay logic symbols with solid-state logic symbols

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Describe what is meant by sequence control.
2. Referring to the diagram in figure 21-2, explain what will happen if the motor on the coil (M) becomes overloaded. *Circuit will stop*
3. In figure 21-2, what will happen if there is an overload on the motor starter (M2)?
Start Contacts Close
4. What is the sequence of operation in figure 21-2?
5. Redraw figure 21-3 so that if the feed motor (M3) is tripped out because of overload, it will also stop the main drive motor (M2).
6. Draw a symbol for a solid-state logic element "AND."

UNIT 22 Time-delay, Low-voltage Release Relay

Objectives After studying this unit, the student will be able to:

- Describe the purpose of a time-delay, low-voltage release relay
- Describe the construction and operation of a time-delay, low-voltage release relay
- Make proper connections to insert this type of relay in a circuit that contains a motor starter and a push-button station
- Read and interpret control diagrams of low-voltage release relay

There is a possibility of injury to an operator or damage to machinery when the power suddenly resumes after a prolonged voltage failure. Therefore, it is desirable to provide some means of preventing motors from restarting in such cases. One method of preventing motor restart is known as low-voltage protection or three-wire control. However, three-wire control is not practical since momentary line voltage fluctuations occur in many localities, or the voltage actually fails for only a few seconds. Remember that with three-wire control, each time a voltage failure occurs the motors must be restarted manually. This is a time-consuming procedure and, in some instances, can cause damage to material in process or production.

One solution to this problem is to use a time-delay, low-voltage release device, figure 22-1. When this device is used with a magnetic starter and a momentary contact push-button station, the motor is automatically reconnected to the power lines after a voltage failure of short duration. If the voltage failure exceeds the time-delay setting of the low-voltage release device, or if the

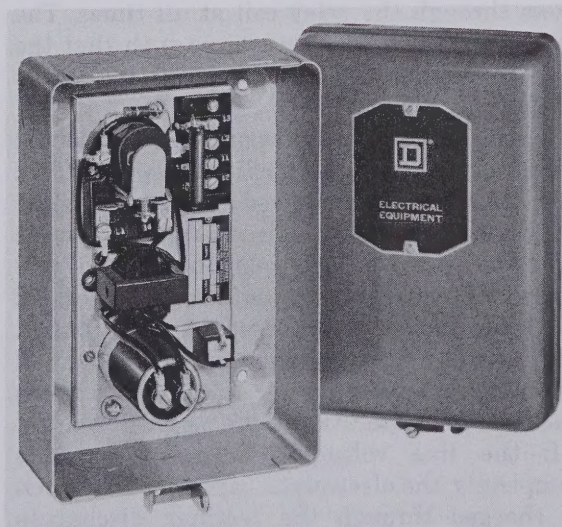


FIG. 22-1 Time-delay, low-voltage release relay (Courtesy Square D Co.)

stop button is pressed, the motor will not restart automatically; it must be restarted by pressing the start button. As a result, the use of a time-delay, low-voltage release device provides the safety of three-wire control. In addition, it eliminates the inconvenience of a loss of production time where momentary voltage failures are common.

CONSTRUCTION AND OPERATION

The time-delay, low-voltage release device consists of a single-pole, normally open control relay, an electrolytic capacitor, a rectifier, two resistors, and a control transformer, figure 22-2. Resistor R1 is connected in parallel with the coil of the control relay CR1 to provide a time delay of approximately two seconds. Removal of this resistor provides a time delay of approximately four seconds.

When used with a magnetic starter and a momentary contact, start-stop push-button station, the coil of the low-voltage release relay is connected to the secondary of the transformer through the rectifier and a resistor. Current flows through the relay coil at all times. The value of resistor R2, however, is such that the current flowing through the coil is too low to allow relay pickup.

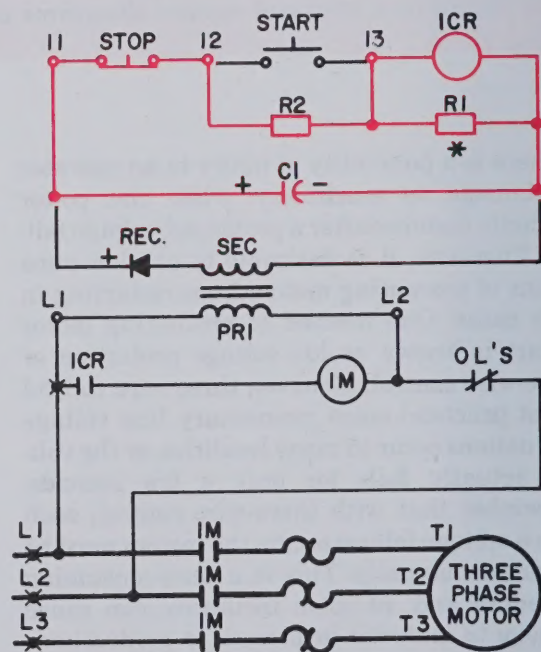
When the start button is pressed, resistor R2 is cut out, full voltage is applied to the relay coil, and the relay is energized. (When the start button is released, the resistor is again in series with the relay coil. The relay, however, is still energized since less current is required to hold the relay once it is picked up.) A relay contact 1CR is wired in series with the operating coil 1M of the magnetic starter. This contact closes and allows the operation of the magnetic starter.

If the line voltage is reduced or fails completely, the electrolytic capacitor C1, which is charged through the rectifier, discharges through the control relay coil to keep the coil

energized. The time required for the capacitor to discharge is a function of the resistance in the circuit and the capacitance of the device.

If the line voltage returns to approximately 85 percent of its normal value before the capacitor is discharged, the magnetic starter automatically recloses and restarts the motor. If the voltage does not return to normal before the capacitor is discharged, the control relay opens. As a result, to restart the motor the push button must be pressed when power is returned.

At any time, pushing the stop button causes the control relay to be de-energized. The starter circuit then opens immediately.



- ✱ INDICATES TERMINALS ON MAGNETIC STARTER.
- ✱ TO INCREASE TIME DELAY REMOVE RESISTOR R1.
- INDICATES TERMINALS ON TIME-DELAY, LOW-VOLTAGE RELEASE.

FIG. 22-2 Elementary diagram of low-voltage release relay in figure 22-1

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. In the event of line voltage fluctuations or failure, how is the starter maintained in a closed position? *Starter is not maintained*

2. How is this principle applied to a dc starter? *Capacitor holds contacts engaged*

3. Under what condition will the motor restart automatically after a voltage failure?

4. Explain in detail the purpose of a time-delay, low-voltage release relay assembly installed in a motor control circuit. *If failure time is less than delay time - before capacitor discharges*

To maintain a control circuit for a few seconds in the event of a momentary loss or drop in voltage. Motor will restart if current is returned within designated time-delay.

SECTION FIVE

AC REDUCED VOLTAGE STARTERS

- UNIT 23** The Motor and Starting Methods
- UNIT 24** Primary Resistor-type Starters
- UNIT 25** Autotransformer Starters
- UNIT 26** Part Winding Motor Starters
- UNIT 27** Automatic Starters for Star-Delta Motors
- UNIT 28** AC Solid-State Reduced Voltage Controller

UNIT 23 The Motor and Starting Methods

Objectives After studying this unit, the student will be able to:

- Describe the most important factors to consider when selecting motor starting equipment
- State why reduced current starting is important
- Describe typical starting methods
- Identify squirrel cage induction motors
- Describe how a squirrel cage motor functions

There are two reasons for the use of reduced voltage starting:

1. To reduce the high starting current drawn by the motor.
2. To reduce the starting torque provided by the motor.

The simplicity, ruggedness, and reliability of squirrel cage induction motors have made them the standard choice for alternating-current, all-purpose, constant speed motor applications. Several types of motors are available; therefore, various kinds of starting methods and control equipment are also obtainable.

THE MOTOR

The Revolving Field

The squirrel cage motor consists of a frame, a stator, and a rotor. The *stator*, or stationary portion carries the stator windings, figure 23-1 (center). The *rotor* is a rotating member, figure

23-1 (bottom) which is constructed of steel laminations mounted rigidly on the motor shaft. The rotor winding consists of many copper, or aluminum, bars fitted into slots in the rotor. The bars are connected at each end by a closed continuous ring. The assembly of the rotor bars and end rings resembles a squirrel cage. This similarity gives the motor its name, *squirrel cage motor*.

For a three-phase motor, the stator frame has three windings. The stator for a squirrel cage motor never has fewer than two poles. The stator windings are connected to the power source. When a 60-hertz current flows in the stator winding, a magnetic field is produced. Because of the three-phase alternating current and the displacement of each phase winding, this field circles the rotor at a speed equal to the number of revolutions per minute (r/min or rpm) divided by the number of pairs of stator poles. Therefore, on 60 hertz, a motor having one pair of two poles will run at 3600 r/min; a four-pole motor (two pairs of two poles each) will run at 1800 r/min ($3600/2$). The revolving stator magnetic field

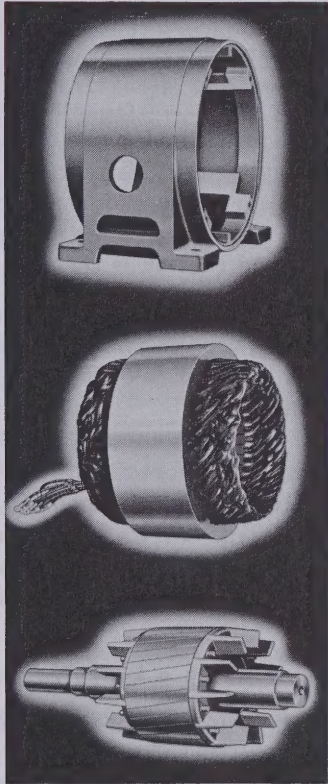


FIG. 23-1 Squirrel cage induction motor frame, stator, and rotor. Note the cooling blades on rotor. (Courtesy U.S. Electrical Motors)

induces current in the short-circuited rotor bars. The induced current in the squirrel cage then has a magnetic field of its own. The two fields interact, with the rotor field following the stator rotating field, thereby establishing a torque on the motor shaft. The current induced has its largest value when the rotor is at a standstill. The current then decreases as the motor comes up to speed. In designing motors for specific applications, changing the resistance and reactance of the rotor will alter the characteristics of the motor. For any one rotor design, however, the characteristics are fixed. There are no external connections to the rotor. A cutaway view of an assembled squirrel cage motor is shown in figure 23-2.

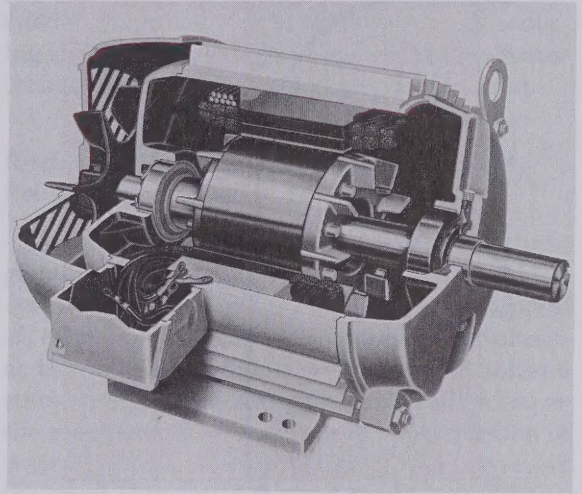


FIG. 23-2 Cutaway view of a squirrel cage motor (Courtesy U.S. Electrical Motors)

Locked Rotor Currents

The locked rotor current and the resulting torque are factors which determine if the motor can be connected across the line or if the current must be reduced to obtain the required performance. Locked rotor currents for different motor types vary from $2\frac{1}{2}$ to 10 times the full-load current of the motor. Some motors, however, have even higher inrush currents.

The Induction Motor At Start

Figure 23-3 illustrates the behavior of the current taken by an induction motor at various speeds. First, note that the starting current is high compared to the running current. In addition, the starting current remains fairly constant at this high value as the motor speed increases. The current then drops sharply as the motor approaches its full rated speed. Since the motor heating rate is a function of I^2 (copper loss), this rate is high during acceleration. For most of the acceleration period, the motor can be considered to be in the locked condition.

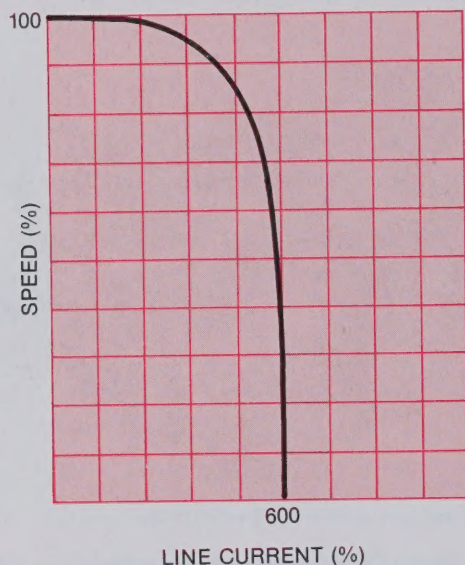


FIG. 23-3 Induction motor current at various speeds

No-Load Rotor Speed

The induced current in the rotor gives rise to magnetic forces which cause the rotor to turn in the direction of rotation of the stator field. The motor accelerates until the necessary speed is reached to overcome windage and friction losses. This speed is referred to as the *no-load speed*. The motor never reaches synchronous speed since a current will not be induced in the rotor under these conditions and thus the motor will not produce a torque. *Torque* refers to the twisting or turning of the motor shaft. (The rotor bars of the squirrel cage must be cut by the rotating magnetic ac field to produce a torque.)

Speed Under Load

As the rotor slows down under load, the speed adjusts itself to the point where the forces exerted by the magnetic field on the rotor are sufficient to overcome the torque required by the load. *Slip* is the term given to the difference between the speed of the magnetic field and the speed of the rotor.

The slip necessary to carry the full load depends on the characteristics of the motor. In general, the following situations are true:

1. The higher the inrush current, the lower the slip at which the motor can carry full load, and the higher the efficiency.
2. The lower the value of inrush current, the higher the slip at which the motor can carry full load, and the lower the efficiency.

An increase in line voltage causes a decrease in the slip, and a decrease in line voltage causes an increase in the slip. In either case, sufficient current is induced in the rotor to carry the load. A decrease in the line voltage causes an increase in the heating of the motor. An increase in the line voltage decreases the heating. In other words, the motor can carry a larger load. The slip at rated load may vary from 3 percent to 20 percent for different types of motors.

Variation of Torque Requirements

Different loads have different torque requirements. This must be kept in mind when considering the starting torque required and the rate of acceleration most desirable for the load. In general, a number of motors will satisfy the load requirements of an installation under normal running conditions. However, it may be more difficult to use a motor that will perform satisfactorily during both starting and running. Often, it is necessary to decide which is the more important factor to consider for a particular application. For example, a motor may be selected to give the best starting performance, but there may be a sacrifice in the running efficiency. In another case, to obtain a high running efficiency, it may be necessary to use a motor with a high current inrush. For these and other examples, the selection of the proper starter to overcome the objectionable features is an important consideration in view of the high cost of energy today.

The machine to which the motor is connected may be started at no load, normal load, or over-

load conditions. Many industrial applications require that the machine be started when it is not loaded. Thus, the only torque required is that necessary to overcome the inertia of the machine. Other applications may require that the motor be started while the machine it is driving is subjected to the same load it handles during normal running. In this instance, the starting requirements include the ability to overcome both the normal load and the starting inertia.

Important factors in providing the proper starting equipment include using a starter that satisfies the horsepower rating of the motor, and connecting the motor directly across the line. Another factor is that the motor itself must meet the torque requirements of the industrial application. Actually, the starting equipment may be selected to provide adequate control of the torque after the motor is selected.

Controlling Torque

The most common method of starting a poly-phase, squirrel cage induction motor is to connect the motor directly to the plant distribution system at full voltage. In this case a manual or a magnetic starter is used. From the standpoint of the motor itself, this is a perfectly acceptable practice. As a matter of fact, it is probably the most desirable method of starting this type of motor.

Overload protective devices have reached such a degree of reliability that the motor is given every opportunity to make a safe start. The application of a reduced voltage to a motor in an attempt to prevent overheating during acceleration is generally wasted effort. The accelerating time will increase and correctly sized overload elements may still trip.

Reduced voltage starting minimizes the shock on the driven machine by reducing the starting torque of the motor. A high torque, applied suddenly, with full voltage starting, may cause belts to slip and wear or may damage gears, chains, or couplings. The material being

processed, or conveyed, may be damaged by the suddenly applied jerk of high torque. By reducing the starting voltage, or current, at the motor terminals, the starting torque is decreased.

Reduced Voltage, Reduced Current, Reduced Torque

The category of reduced voltage methods generally includes all starting methods which deviate from standard, line voltage starting. Not all of these starting schemes reduce the voltage at the motor terminals. Even reduced voltage starters reduce the voltage only to achieve either the reduction of line current or the reduction of starting torque. The reduction of line current is the most commonly desired result.

You should note one important point: *When the voltage is reduced to start a motor, the current is also reduced, and so is the torque that the machine can deliver.* Regardless of the desired result (either reduced current or reduced torque), remember that the other will always follow.

If this fact is kept in mind, it is apparent that a motor which will not start a load on full voltage can not start that same load at reduced voltage or reduced current conditions. Any attempt to use a reduced voltage or current scheme will not be successful in accelerating troublesome loads. The very process of reducing the voltage and current will further reduce the available starting torque.

Need for Reduced Current Starting

The most common function of reduced voltage starting devices is to reduce, or in some way modify, the starting current of an induction motor. In other words, the rate of change of the starting current is confined to prescribed limits, or there is a predetermined current-time picture that the motor presents to the supply wiring network.

A current-time picture for an entire area is maintained and regulated by the public power utility serving the area. The power company

attempts to maintain a reasonably constant voltage at the points of supply so that lamp flicker will not be noticeable. The success of the power company in this attempt depends on the generating capacity to the area; transformer and line loading conditions and adequacies; and the automatic voltage regulating equipment in use. Voltage regulation also depends on the sudden demands imposed on the supply facilities by residential, commercial, and industrial customers. Transient overloading of the power supply may be caused by: (1) sudden high surges of reactive current from large motors on starting, (2) pulsations in current taken by electrical machinery driving reciprocating compressors and similar machinery, (3) the impulse demands of industrial x-ray equipment, and (4) the variable power factor of electric furnaces. All of these demands are capable of producing voltage fluctuations.

Therefore, each of these particularly difficult loads is regulated in some way by the power utility. The utility requires the use of some form of reduced voltage, reduced current method and helps its customers determine the best method.

Power company rules and regulations vary between individual companies and the areas served. The following list gives some commonly applied regulations. (All of the possible restrictions on energy usage are not given.) An installation may be governed by just one of these restrictions, or two or more rules may be combined. Regulations include:

1. A maximum number of starting amperes, either per horsepower or per motor.
2. A maximum horsepower for line starting. A limit in percent of full load current is set for anything above this value.
3. A maximum current in amperes for a particular feeder size. It is up to the user to determine if the motor will conform to the power company requirements.
4. A maximum rate of change of line current taken by the motor; for example, 200 amperes per half-second.

It should be apparent that it is very important for the electrician to understand the behavior of an induction motor during the startup and acceleration periods. Such an understanding enables you to select the proper starting method to conform to local power company regulations. Even though several starting methods may appear to be appropriate, a careful examination of the specific application will usually indicate the one best method for motor starting.

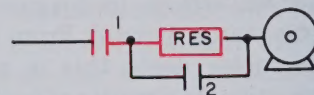
TYPICAL STARTING METHODS

The most common methods of starting polyphase squirrel cage motors include:

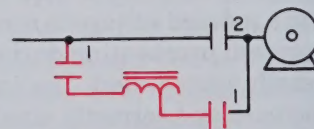
- *Full voltage starting:* a hand-operated or automatic starting switch throws the motor directly across the line.



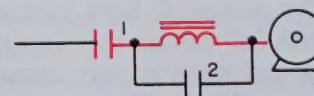
- *Primary resistance starting:* a resistance unit connected in series with the stator reduces the starting current.



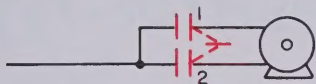
- *Autotransformer or compensator starting:* manual or automatic switching between the taps of the autotransformer gives reduced voltage starting.



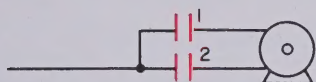
- *Impedance starting:* reactors are used in series with the motor.



- **Star-delta starting:** the stator of the motor is star connected for starting and delta connected for running.

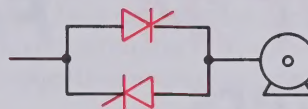


- **Part winding starting:** the stator windings of the motor are made up of two or more circuits; the individual circuits are connected to the line in series for starting and in parallel for normal operation.



- **Solid-state electronic control:** Control of current or acceleration time is achieved by

gating silicon controlled rectifiers with the ac half cycle.



Of these methods, the two most fundamental ways of starting squirrel cage motors are full voltage starting and reduced voltage starting. Once again, full voltage starting can be used where the driven load can stand the shock of starting and objectionable line disturbances are not created. Reduced voltage starting may be required if the starting torque must be applied gradually or if the starting current produces objectionable line disturbances.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. List five commonly used starting methods.
2. When can full voltage starting be used? *When maximum torque will not harm equipment - no objectionable line disturbances*
3. Name the simplest, most rugged and reliable ac motor. Describe how it operates. *Squirrel Cage - Magnetic Field*
4. Describe the term, slip. *Difference between Rotor Pole + Stator Pole*
5. When the voltage is reduced to start a motor, what happens to the
 - a. torque? *reduced*
 - b. current? *reduced*
6. Why is it more advisable to start some machines at reduced torque? *To save machine drives (belts + chains)*

UNIT 24 Primary Resistor-type Starters

Objectives After studying this unit, the student will be able to:

- State why reduced current starting is important
- Describe the construction and operation of primary resistor starters
- Interpret and draw diagrams for primary resistor starters
- Connect squirrel cage motors to primary resistor starters
- Troubleshoot electrical problems on primary resistor starters

PRIMARY RESISTOR-TYPE STARTERS

A simple and common method of starting a motor at reduced voltage is used in primary resistor-type starters. In this method, a resistor is connected in series in the lines to the motor, figure 24-1. Thus, there is a voltage drop across the resistors and the voltage is reduced at the motor terminals. Reduced motor starting speed and current are the result. As the motor accelerates, the current through the resistor decreases, reducing the voltage drop ($E = IR$) and increasing the voltage across the motor terminals. A smooth acceleration is obtained with gradually increasing torque and voltage.

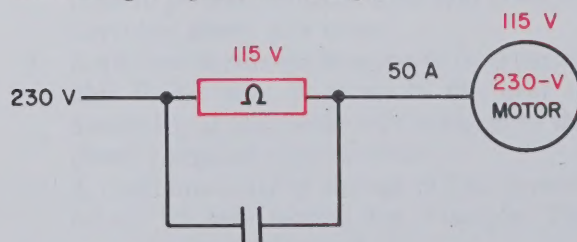


FIG. 24-1 Reduced voltage starting

The resistance is disconnected when the motor reaches a certain speed. The motor is then connected to run on full line voltage, figure 24-2. The introduction and removal of resistance in the motor starting circuit may be accomplished manually or automatically.

Primary resistor starters are used to start squirrel cage motors in situations where limited torque is required to prevent damage to driven machinery. These starters are also used with limited current inrush to prevent excessive power line disturbances.

It is desirable to limit the starting current in the following cases:

1. When the power system does not have the capacity for full voltage starting.
2. When full voltage starting may cause serious line disturbances, such as in lighting circuits, electronic circuits, the simultaneous starting of many motors, or the motor is distant from the incoming power supply.

In these situations, reduced voltage starters may be recommended for motors with ratings as small as five horsepower.

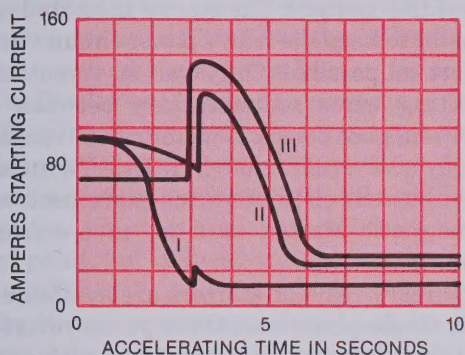


FIG. 24-2 The curves illustrate how a primary resistance starter reduces the starting current of a 10 hp, 230-volt motor under three different load conditions. Curve I is at a light load and Curve II is at a heavy load. In either case, the running switch closes after three seconds. With a heavy load, an increase in the starting time reduces the second current inrush; the motor will reach a higher speed before it is connected to full line voltage. In Curve III the motor cannot start on the current allowed through the resistance; it comes up to speed only after connection to full line voltage.

Reduced voltage starting must be used for driving machinery which must not be subjected to a sudden high starting torque and the shock of sudden acceleration. Among typical applications are those where belt drives may slip or where large gears, fan blades, or couplings may be damaged by sudden starts.

Automatic primary resistor starters may use one or more than one step of acceleration, depending upon the size of the motor being controlled. These starters provide smooth acceleration without the line current surges normally experienced when switching auto-transformer types of reduced voltage starters.

Primary resistor starters provide closed transition starting. This means the motor is never disconnected from the line from the moment it is first connected until the motor is operating at full line voltage. This feature may be important in wiring systems sensitive to voltage changes. Primary resistor starters do consume energy, with the energy being dissipated as heat.

However, the motor starts at a much higher power factor than with other starting methods.

Special starters are required for very high inertia loads with long acceleration periods or where power companies require that current surges be limited to specific increments at stated intervals.

Primary Resistor-type Reduced Voltage Starter

Figures 24-3 and 24-4 illustrate an automatic, primary resistor-type, reduced voltage starter. Figure 24-4 shows the starter with two-point acceleration connected to a three-phase, squirrel cage induction motor.

When the start button is pressed, a complete circuit is established from L1 through the stop button, start button, coil M, and the overload relay contacts to L2. When coil (M) is energized, the main power contacts (M) and the control circuit maintaining contact (M) are closed. The motor is energized through the overload heaters and the starting resistors. Because the resistors are connected in series with the motor terminals,

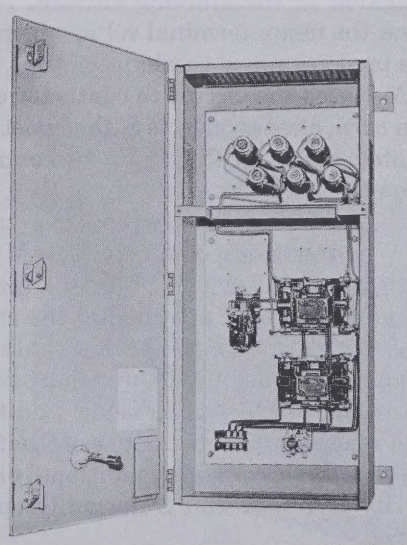


FIG. 24-3 Reduced voltage, primary resistance-type starter. Resistors are in the top, ventilated system. (Courtesy EATON Corp., Cutler-Hammer Products)

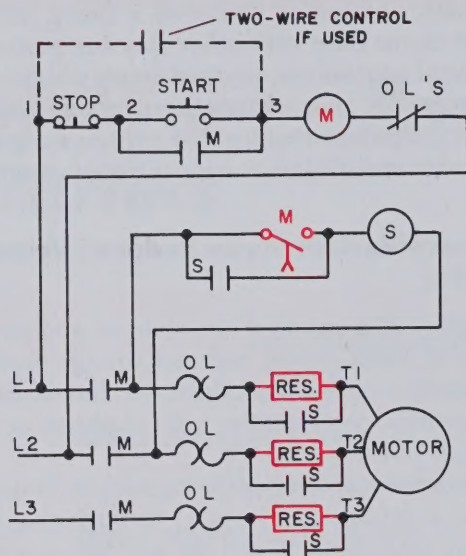


FIG. 24-4 Line diagram of primary resistor starter with two-step acceleration

a voltage drop occurs in the resistors and the motor starts on reduced voltage.

As the motor accelerates, the voltage drop across the resistors decreases gradually because of a reduction in the starting current. At the same time, the motor terminal voltage increases.

After a predetermined acceleration time, delay contact M closes the circuit to contactor coil S. Coil S, in turn, closes contacts S, the resistances are shunted out, and the motor is connected across the full line voltage.

Note that the stop button controls coil M directly. When the main power contacts M open, coil S drops out. After coil M is energized, a pneumatic timing unit attached to the starter unit M retards the closing of time contact M. This scheme uses starter M for dual purpose and eliminates one coil, a timing relay. Additional control contact (S) connected in parallel with the on-delay contact (M) provides additional electrical security to insure coil S normally open is maintained.

For maximum operating efficiency, push buttons or other pilot devices are usually mounted on the driven machinery within easy

reach of the operator. The starter is located near the motor to keep the heavy power circuit wiring as short as possible. Only two or three small connecting wires are necessary between the starter and pilot device. A motor can be operated from any of several remote locations if a number of push buttons or pilot switches are used with one magnetic starter, such as on a conveyor system.

Ac primary resistor starters are available for use on single-phase and three-phase reversing operations. They are also available with multiple points of acceleration.

Four-point Resistor Starter

Figure 24-5 elementary diagram illustrates a four-point resistor starter. Operating the start button energizes contactor S1, connecting the motor to the line. The total resistance is in each line. The mechanically operated timer S1 closes to energize contactor S2. The closing of contacts S2 shunts out a portion of the starting resistor.

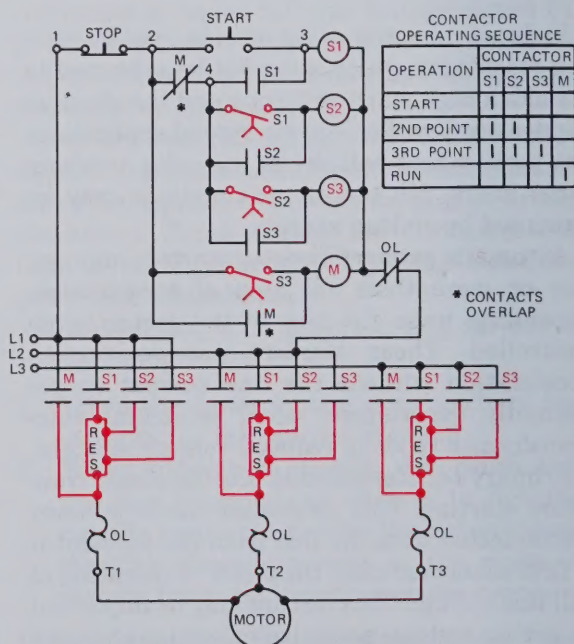


FIG. 24-5 Schematic diagram of a four-point primary resistor starter

The mechanically operated timer S2 closes to energize contactor S3. The closing of contacts S3 shunts out additional resistance in the resistor bank. The timer S3 closes to energize contactor M. The closing of contacts M connects the motor at full voltage. An electrical interlock on M then opens to drop out contactors S1, S2, and S3. The rotor may not start turning until the second or third point, but reduced voltage will have been accomplished.

The timers or timing relays used are of the preset time type such as pneumatic, dash-pot or solid-state timers. Compensating-type current relays are also used.

Figure 24-6 shows two types of resistor banks used to start small motors. The resistors (shown in A of figure 24-6) consist of resistance wire wound around porcelain bases and imbedded in refractory cement. The other resistor (B of figure 24-6) has a ribbon-type construction and is used on larger motor starters. This type of resistor consists of an alloy ribbon formed in a zig-zag shape. The formed ribbon is supported between porcelain blocks which have recesses for each

bend of the ribbon. The ribbons are not stressed and do not have a reduced cross section, since they are bent on the flat and not on the edge. Any number of units can be combined vertically or horizontally, in series or in parallel.

Some starters have graphite compression disk resistors and are used for starting poly-phase squirrel cage motors, figure 24-7.

A primary resistance-type starter has the following features:

- simple construction
- low initial cost
- low maintenance
- smooth acceleration in operation
- continuous connection of the motor to the line during the starting period
- a high power factor.

These starters should *not* be used for starting *very heavy* loads because of their low starting torque. These starters are said to have a low starting economy because the starting resistors dissipate electrical energy.

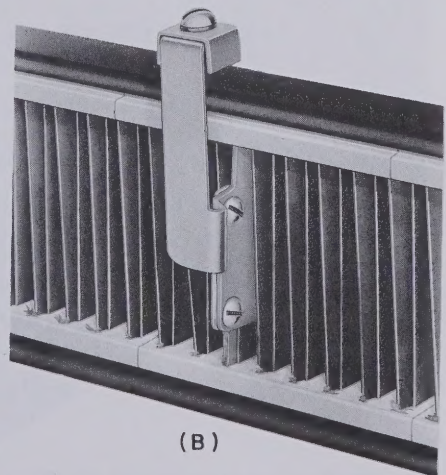
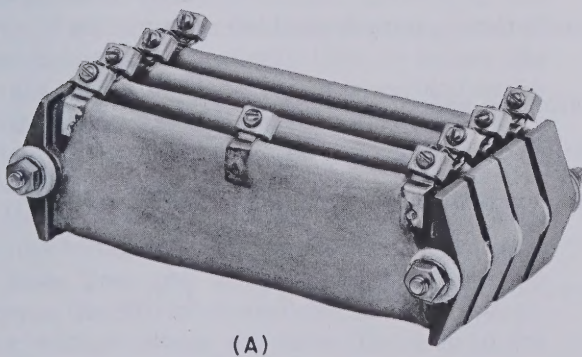


FIG. 24-6 Resistors used in primary resistor-type starters. Ribbon resistor is used with larger starters. (Courtesy Square D Co.)

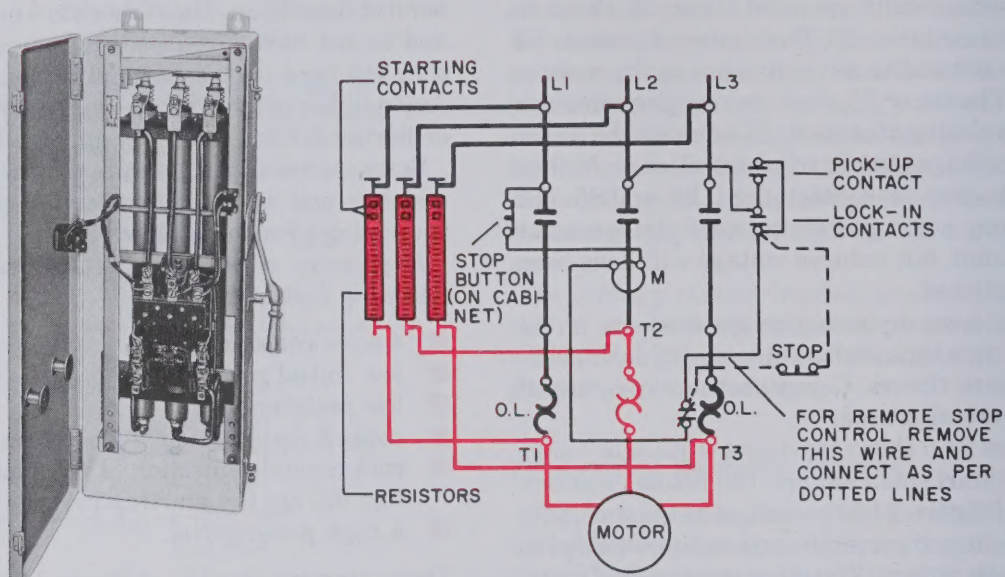


FIG. 24-7 Manual resistance starter with "carbon pile" resistors (Courtesy Allen-Bradley Co.)

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What is the purpose of inserting resistance in the stator circuit during starting?
To Reduce Starting Voltage
2. Why is the power not interrupted when the motor makes the transition from start to run?
The starter contacts are engaged
3. If the starter is to function properly and a timing relay is used, where must the coil of the relay be connected?
4. How may additional steps of acceleration be added?
Connecting more Timers or Resistor in series
5. What is meant by the low or poor starting economy of a primary resistor starter?
Power is lost through Resistors as heat
6. How does this starter provide smooth acceleration and a gradual increase of torque?
Starts with low voltage to the motor and gradually increases to full line load.

UNIT 25 Autotransformer Starters

Objectives After studying this unit, the student will be able to:

- Describe the construction and operation of autotransformer starters
- Draw and interpret diagrams for autotransformer starters
- Connect squirrel cage motors to autotransformer starters
- Define what is meant by open transition and closed transition starting
- Troubleshoot electrical problems on autotransformer starters

Autotransformer reduced voltage starters are similar to primary resistor starters in that they are used primarily with ac squirrel cage motors to limit the inrush current or to lessen the starting strain on driven machinery, figure 25-1. This type of starter uses autotransformers between the motor and the supply lines to reduce the motor starting voltage. Taps are provided on the autotransformer to permit the user to start the motor at approximately 50%, 65%, or 80% of line voltage.

Most motors are successfully started at 65% of line voltage. In situations where this value of voltage does not provide sufficient starting torque, the 80% tap is available. If the 50% starting voltage creates excessive line drop to the motor, the 65% taps are available. This way of changing the starting voltage is not usually available with other types of starters. The starting transformers are inductive loads; therefore, they momentarily affect the power factor. They are suitable for long starting periods, however.

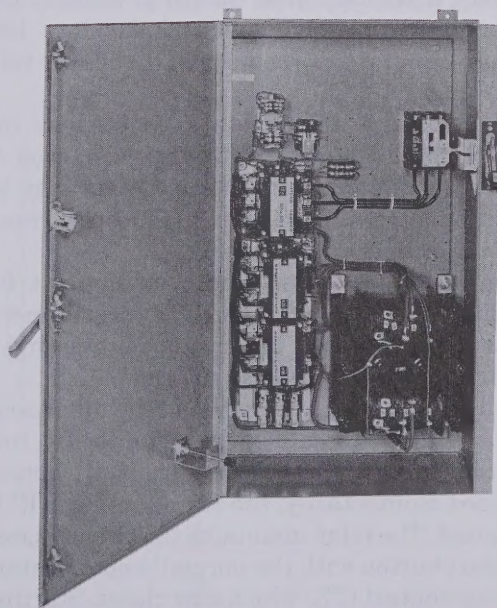


FIG. 25-1 Reduced voltage autotransformer starter, size 3 (Courtesy of EATON Corp., Cutler-Hammer Products)

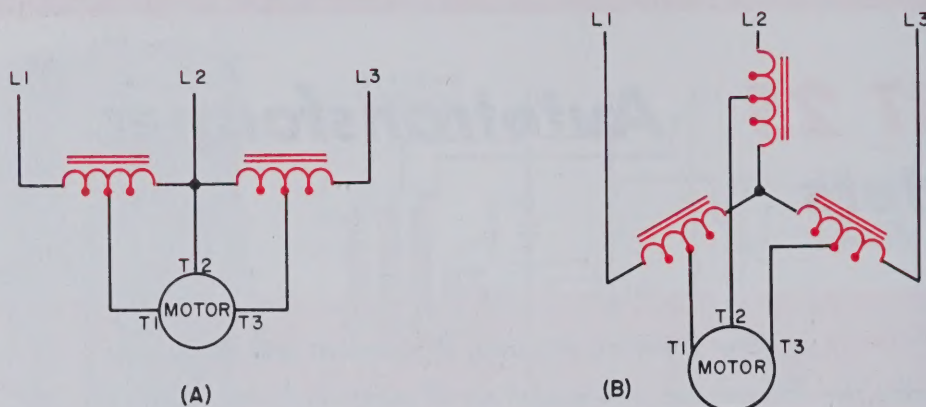


FIG. 25-2 Power circuit connections showing two and three autotransformers used for reduced voltage starting

Autotransformer Starters

To reduce the voltage across the motor terminals during the accelerating period, an autotransformer-type starter generally has two autotransformers connected in open delta. During the reduced voltage starting period, the motor is connected to the taps on the autotransformer. With the lower starting voltage, the motor draws less current and develops less torque than if it were connected to the line voltage, figure 25-2.

An adjustable time-delay relay controls the transfer from the reduced voltage condition to full voltage. A current-sensitive relay may be used to control the transfer to obtain current-limiting acceleration.

Figure 25-2(A) shows the power circuit for starting the motor with two autotransformers. Figure 25-2(B) shows the circuit for starting a motor with three autotransformers.

To understand the operation of the autotransformer starter more clearly, refer to the line diagram in figure 25-3. When the start button is closed momentarily, the timing relay (TR) is energized. The relay maintains the circuit across the start button with the normally open instantaneous contact (TR) which now closes. Starting coil (S) is energized from terminal four through the normally closed "time delay in opening" contact (TR), through the normally closed inter-

lock (R), through the coil S, and through the overload contact to L2, completing the circuit. The running starter can not be closed at this point because the normally closed interlock S is open and the mechanical interlock is operating.

After a preset timing period (TR), the normally closed contacts open and the normally open (TR) contacts close. When the coil S is de-energized, normally closed interlock S closes and energizes the running starter R.

The contact switching arrangement for a typical power circuit is shown in figure 25-3. When two transformers are used, there will be an imbalance in the motor voltage during starting. This imbalance will produce a torque variation of approximately 10 percent. In the running position, the motor is connected directly across the line and the autotransformers are disconnected from the line. As a result, only three contacts are shown.

Full line voltage is applied to the outside terminals of the autotransformer on starting. Reduced voltage for starting the motor is obtained from the autotransformer taps. The current taken by a motor varies directly with the applied voltage.

Starting compensators (autotransformer starters) using a five-pole starting contactor are classified as open transition starters. The motor is disconnected momentarily from the line

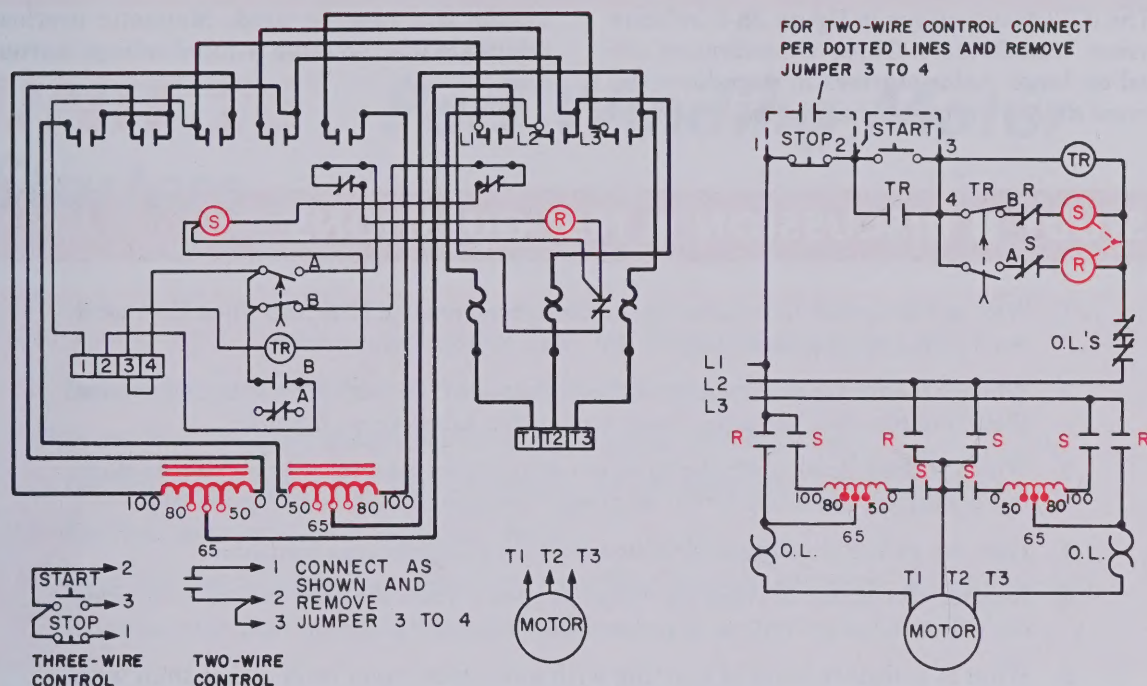


FIG. 25-3 Autotransformer starters provide greater starting torque per ampere drawn from the line than any other type of reduced voltage starter. A typical wiring diagram, similar to that for the device shown in figure 25-1, is shown on left. The line diagram is shown on the right.

during the transfer from the start to the run conditions.

Closed transition connections are usually found on standard size 6 and larger starters. For the closed transition starter, figure 25-4, the starting contactors consist of a three-pole (S2) and a two-pole (S1) contactor operating independently of each other. During the transfer from start to run, the two-pole contactor is open and the three-pole contactor remains closed. The motor continues to accelerate with the autotransformer serving as a reactor. With this type of starter, the motor is not disconnected from the line during the transfer period. Thus, there is less line disturbance and a smoother acceleration.

The transformers are de-energized while in the running position. This is done to conserve electrical energy and to extend their life.

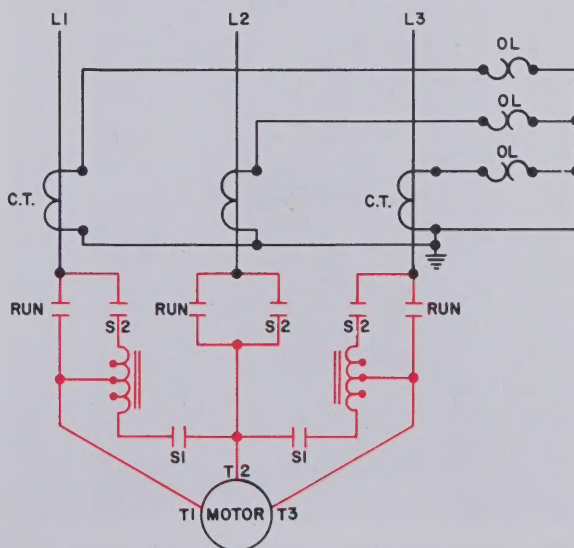


FIG. 25-4 Closed transition (Korndorfer) connection

The (CT) designations in figure 25-4 indicate current transformers. These transformers are used on large motor starters to step down the current so that a conventional overload relay and

heater size may be used. Magnetic overload relays are used on large reduced voltage starters also.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Why is it desirable to remove the autotransformers from the line when the motor reaches its rated speed? *Save Energy*
2. What is meant by an "open transition" from start to run? Why is this condition objectionable at times when used with large horsepower motors?
Moderate loss of current when starter changes
3. Which of the following applies to an autotransformer starter with a five-pole starting contactor: open transition or closed transition? Locate in figure 25-3.
4. How are reduced voltages obtained from autotransformer starters?
The Taps on Transformer
5. Assume the motor is running. What happens when the stop button is pressed and then the start button is pressed immediately?
6. What is a disadvantage of starting with autotransformer coils rather than with resistors? *Auto transformer adds to Inductor load*
7. What is one advantage of using an autotransformer starter?
Less Heat
Greater Starting torque

UNIT 26 *Part Winding Motor Starters*

Objectives After studying this unit, the student will be able to:

- Describe the construction and operation of a part winding motor starter
- Draw and interpret diagrams for part winding motor starters
- List the advantages and disadvantages of two-step part winding starters
- Connect motors to part winding starters
- Describe the difference between part winding motors and dual voltage motors
- Troubleshoot part winding motor starters

Part winding motors are similar in construction to standard squirrel cage motors. However, part winding motors have two identical windings that may be connected to the power supply in sequence to produce reduced starting current and reduced starting torque. These motor windings are intended to operate in parallel. Since only half of the windings are connected to the supply lines at startup, the method is described as *part winding*. (Many, but not all, dual-voltage, 230/460-volt motors are suitable for part winding starting at 230 volts.) By bringing out leads from each winding, the motor manufacturer enables the windings to be connected in parallel, external to the motor, with the starter (refer to figure 15-11).

Part winding starters, figure 26-1, are designed to be used with squirrel cage motors having two separate and parallel stator windings. In the part winding motor, these windings may be Y-connected or delta-connected, depending upon the motor design. Part winding starters are not

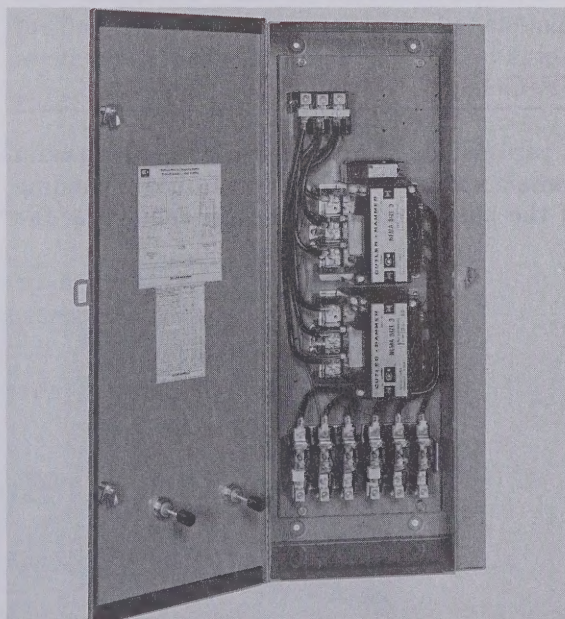


FIG. 26-1 Part winding-type, reduced current starter
(Courtesy of EATON Corp., Cutler-Hammer Products)

suitable for use with delta-wound, dual-voltage motors.

Part winding motors are used to drive centrifugal loads such as fans, blowers, or centrifugal pumps. They are also used for other loads where a reduced starting torque is necessary. This type of motor is also used where the full voltage starting current will produce objectionable voltage drops in the distribution feeders, or where power company restrictions require a reduced starting current. Using a part winding starter to start a motor does not necessarily reduce the maximum starting current. Instead, incremental starting is obtained. Neither one of the two windings has the thermal capacity to operate alone for more than a few seconds. Therefore, unless the motor accelerates to practically full speed on the one winding, the TOTAL current drawn may approach that of line voltage starting.

This type of starting has many applications in air-conditioning systems. This is due to the increased capacity built into these systems and the necessity of limiting both the current and torque upon starting.

TWO-STEP STARTING

A part-winding starter, figure 26-2, has two main contactors. Each contactor controls one winding of the part winding motor. By energizing the

contactors in sequence, first one motor winding is energized, and a short time later the second winding is connected in parallel with the first. As stated previously, the motor is started with one winding energized, giving rise to the name of the starting method part winding starting.

In a two-step part winding starter, figure 26-3, pressing the start button energizes the start contactor (S). As a result, half of the motor windings are connected to the line and a timing relay (TR) is energized. After a time delay of approximately five seconds, the timer contacts (TR) close to energize the “run” contactor. This contactor connects the second half of the motor windings to the line in parallel with the first half of the windings. Note that the control circuit is maintained with an instantaneous normally open contact (TR) operated by the timing relay (TR) and the starting contact (S).

Pressing the stop button or tripping any overload relay disconnects both windings from the line. When starting on one winding, the motor draws approximately two-thirds of the normal locked rotor current, and develops approximately one-half of the normal locked rotor torque.

A two-step part winding starter has certain obvious advantages:

1. It is less expensive. Most other starting methods require additional voltage reducing elements such as transformers, resistors, or reactors.

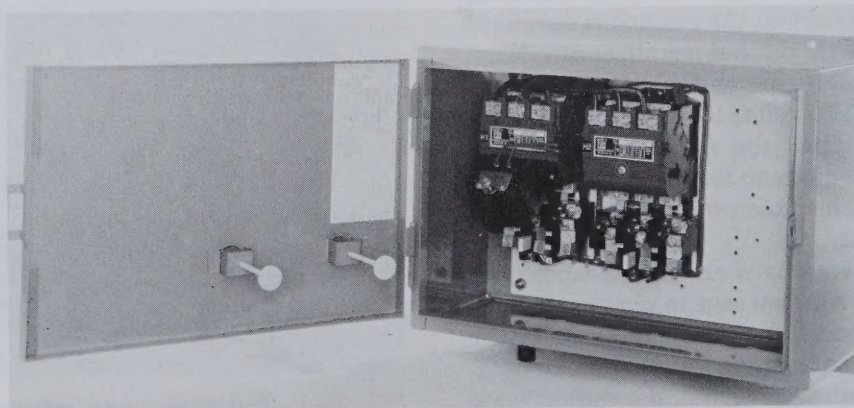


FIG. 26-2 Part winding starter, two step (Courtesy Furnas Electric Company)

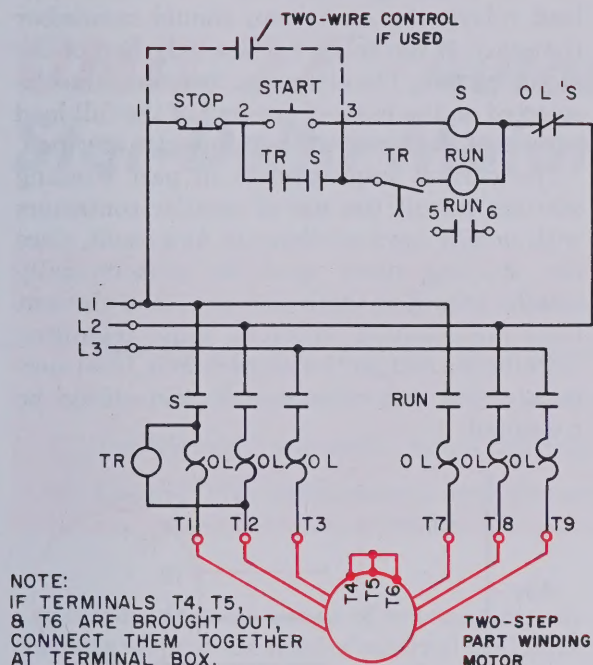


FIG. 26-3 Line diagram of a two-step, part winding starter. When dual-voltage, Y-connected motors are used on the lower voltage only, terminals T4, T5, and T6 are connected to form the center of the second Y.

2. It uses only half-size contactors.
3. It provides closed transition starting.

The two-step part winding starter also has disadvantages:

1. The fixed starting torque is poor.
2. The starter is almost always an incremental start device. It is unsuitable for long starting, high inertia loads.

Part winding starters can not be used in as many applications as other, more expensive types of reduced voltage starters.

THREE-STEP STARTING

The thermal capacity of the motor limits the length of acceleration on the first winding to approximately five seconds, depending upon the connected load. In many instances, the motor will not begin to accelerate until the second winding is connected.

Three-step starting is similar to two-step starting, except that when the first contactor closes, the first winding is connected to the line through a resistor in each phase, figure 26-4. After a time

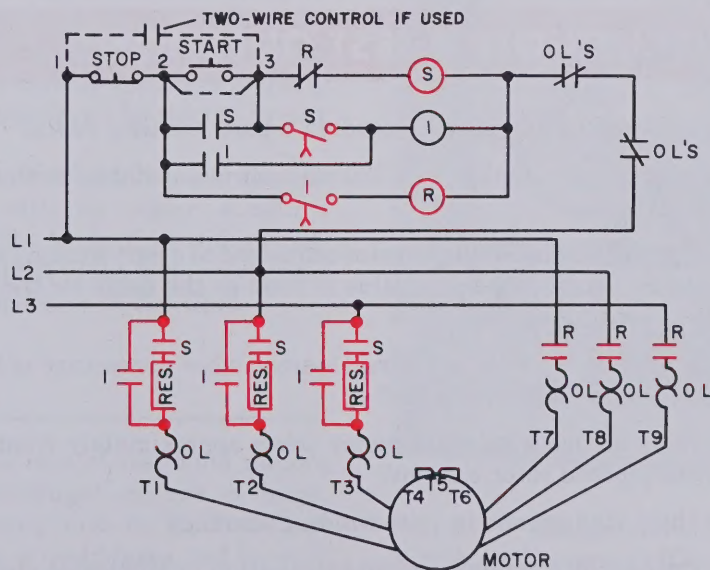


FIG. 26-4 Elementary diagram of a three-step, part winding motor starter

delay of approximately two seconds, this resistor is shunted out and the first winding is connected to the full voltage. After another time delay of about two seconds, the run contactor closes to connect both windings to the line voltage, figure 26-5. The resistors are designed to provide approximately 50 percent of the line voltage to the starting winding. Thus, the motor starts with three approximately equal increments of starting current.

OVERLOAD PROTECTION

Motor overload protection is provided by six overload relays, three in each motor winding. Since the windings are identical, each winding should have the same full-load current. In addition, each phase of the start winding will carry a current identical to that of the corresponding phase in the run winding. Thus, if three overload relays are connected in three phases in the run winding and three other relays are connected in three different phases in the start winding, then the effect of full three-phase protection is obtained.

When selecting heater elements for the overload relays, the electrician should remember that each of the relays carries only half of the motor current. The elements, therefore, must be selected on the basis of one-half of the full-load current of the motor, unless otherwise specified.

The current requirements in part winding starters permit the use of smaller contactors with *smaller overload elements*. As a result, since the starting fuses must be proportionally smaller to protect these elements, dual-element fuses are required. When in doubt regarding installation and protection problems, local electrical codes and ordinances should always be consulted.

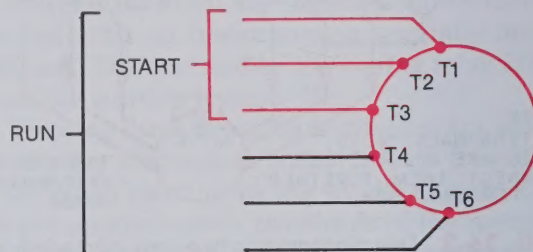


FIG. 26-5 Part winding, single-voltage, star or delta motor terminal markings

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. How can a 230/460-volt motor be used as a part winding motor?
2. Which voltage may be applied to a 230/460-volt motor if used with a part winding starter? Why?
3. If the nameplate of a dual-voltage motor connected to a part winding starter reads 15/30 amperes, which amperage value is used as the basis for the selection of the overload heating elements?
4. If a timing relay fails to cut in the run starter, what percentage of the full-load current can the motor carry safely?
5. When starting on one winding, a motor draws approximately what percentage of the normal locked rotor current?
6. How is a third step gained in part winding starting?
7. Who determines the compliance of an installation to applicable electrical codes with regard to adequate overload or starting and short circuit protection?

UNIT 27 Automatic Starters for Star-Delta Motors

Objectives After studying this unit, the student will be able to:

- Identify terminal markings for a star-delta motor and motor starter
- Describe the purpose and function of star-delta starting
- Troubleshoot star-delta motor starters
- Connect star-delta motors and starters

A commonly used means of reducing inrush currents without the need of external devices is star-delta motor starting (sometimes called wye-delta starting). Figure 27-1 shows a typical star-delta starter.

Star-delta motors are similar in construction to standard squirrel cage motors. However, in star-delta motors, both ends of each of the three windings are brought out to the terminals. If the starter used has the required number of properly wired contacts, the motor can be started in star and run in delta.

The motor must be wound in such a manner that it will run with its stator windings connected in delta. The leads of all of the windings must be brought out to the motor terminals for their proper connection in the field.

APPLICATIONS

The primary applications of star-delta motors are for driving centrifugal chillers of large, central air conditioning units for loads such as fans, blowers, pumps, or centrifuges, and for situations where a reduced starting torque is

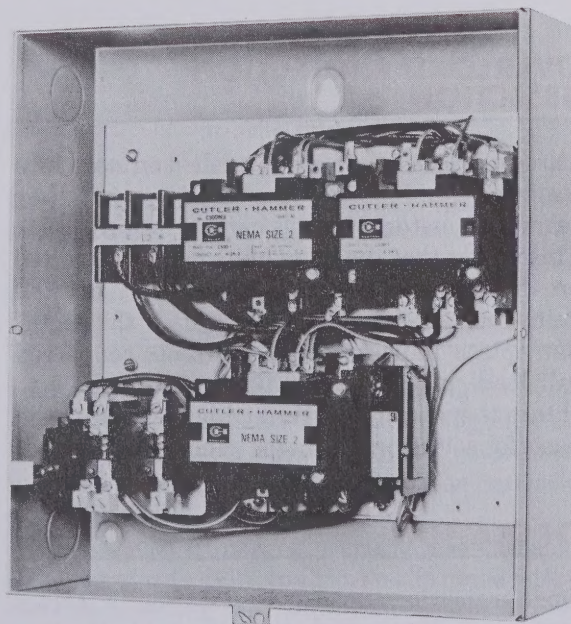


FIG. 27-1 Reduced current star-delta starter, Size 2, NEMA 1 (Courtesy EATON Corp., Cutler-Hammer Products)

necessary. Star-delta motors also may be used where a reduced starting current is required. Since all of the stator winding is used and there are not limiting devices such as resistors or autotransformers, star-delta motors are widely used on loads having high inertia and a long acceleration period.

The speed of a star-delta, squirrel cage induction motor depends upon the number of poles of the motor and the supply line frequency (hertz). Since both of these values are constant, the motor will run at approximately the same speed for either the star or delta connection. The inrush and line current are less when the motor is connected in star than when it is connected in delta. The winding current is less than the line current when the motor is connected in delta. That is, the inrush and line current in the star connection are one-third the values of these quantities in the delta connection. Starting on the higher current delta connection would bump the voltage and create line disturbances.

OVERLOAD PROTECTION SELECTION

Three overload relays are furnished on star-delta starters. These relays are wired so that they carry the motor winding current, figure 27-2. This means that the relay units must be selected on the basis of the winding current, not the delta-connected full load current. If the motor nameplate indicates only the delta-connected full load current, divide this value by 1.73 to obtain the winding current which is used as the basis for selecting the motor winding protection.

OPERATION

Open transition starting for a star-delta starter is shown in figure 27-3. As indicated in the line diagram on the right, the automatic transfer from star to delta is accomplished by a pneumatic timer. The timer is operated by the

movement of the armature of one of the contactors. Operating the push-button station start button energizes contactor S. The main contacts of contactor S connect three of the motor leads together (T4, T5, and T6) to form a star. About the same time, the normally open, control

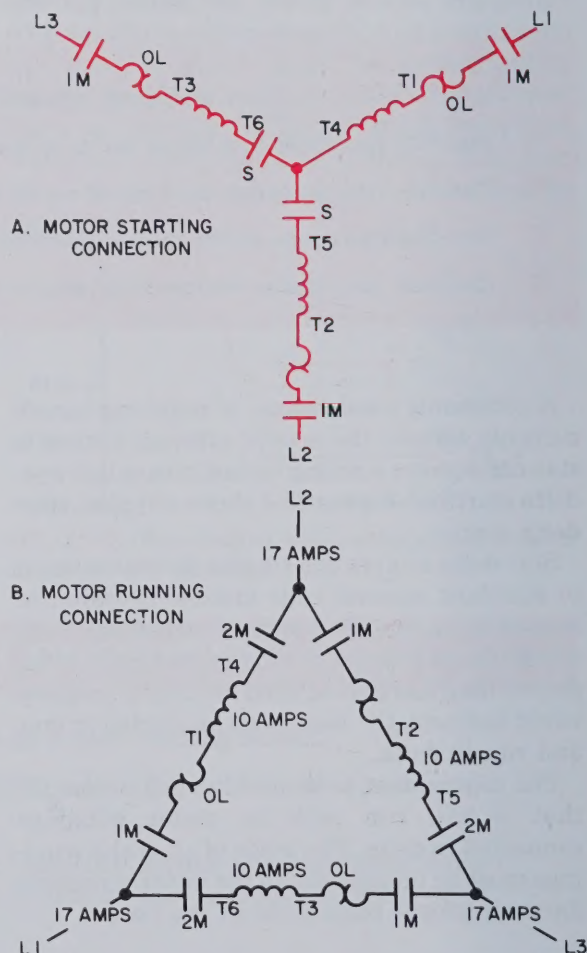


FIG. 27-2 Elementary diagrams of motor power circuits of figure 27-3. Controller connects motor in wye on start and in delta for run. Note that the overload relays are connected in the motor winding circuit, not in the line. Note also that the line current is higher than the phase winding current in the diagram for the delta connection (B). Winding current is the same as the line current in diagram A.

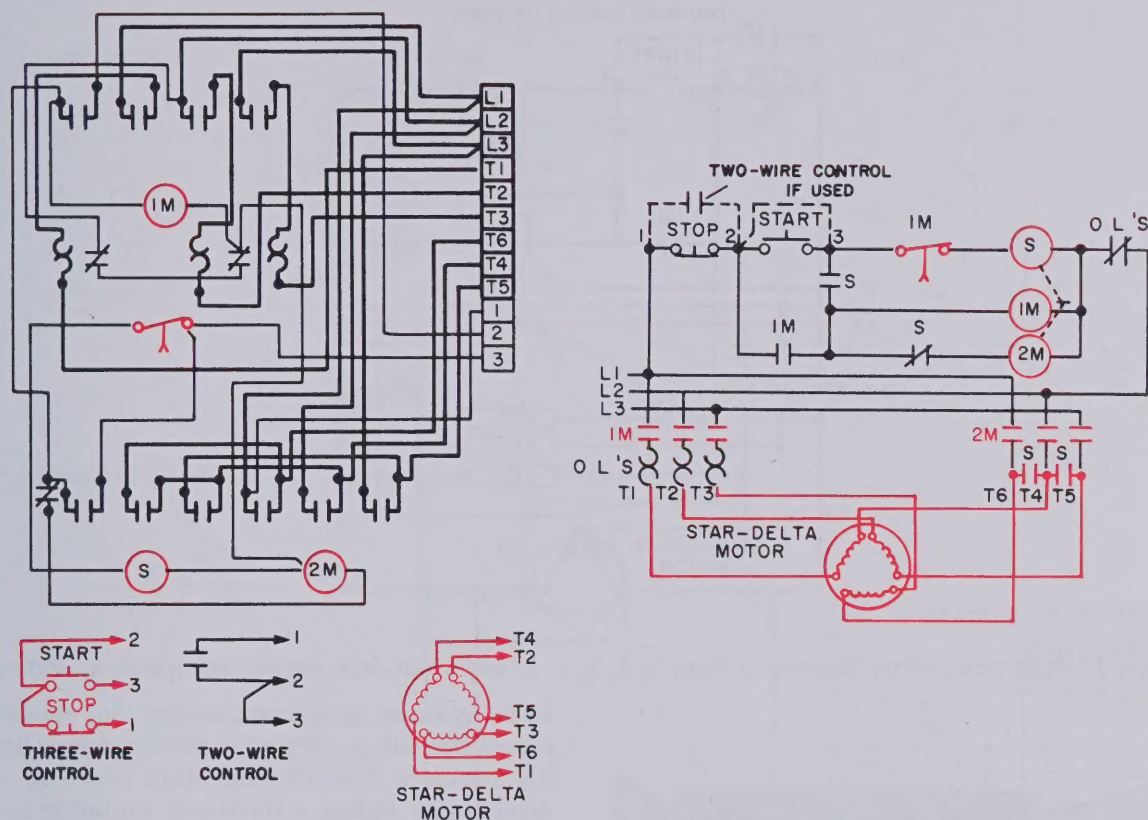


FIG. 27-3 Wiring diagram (left) and line diagram of star-delta starter

contact (S) of the same contactor energizes another contactor (1M) and maintains itself. Since the pneumatic timer is attached to contactor 1M, the motor is connected to the line in star and the timing period is started. When the timing period is complete, the first contactor (S) is de-energized. As a result, normally closed interlock S is closed, and contactor 2M is energized to connect the motor in delta. The motor then runs in the delta-connected configuration. This start-run scheme is called *open transition* because there is a moment in which the motor circuit is open between the opening of the power contacts (S) and the closing of the contacts (2M).

One advantage of this starting method is that it does not require accessory voltage reducing equipment. A star-delta starter has the disadvantage of open circuit transition, but it does

give a larger starting torque per ampere of line current than a part winding starter.

CLOSED TRANSITION STARTING

Figure 27-4 shows a modification of figure 27-3. In figure 27-4, resistors maintain continuity to the motor to avoid the difficulties associated with the open circuit form of transition between start and run.

With closed transition starting, the transfer from the star to delta connections is made without disconnecting the motor from the line. When the transfer from star to delta is made in open transition starting, the starter momentarily disconnects the motor and then reconnects it in delta. While an open transition is satisfactory

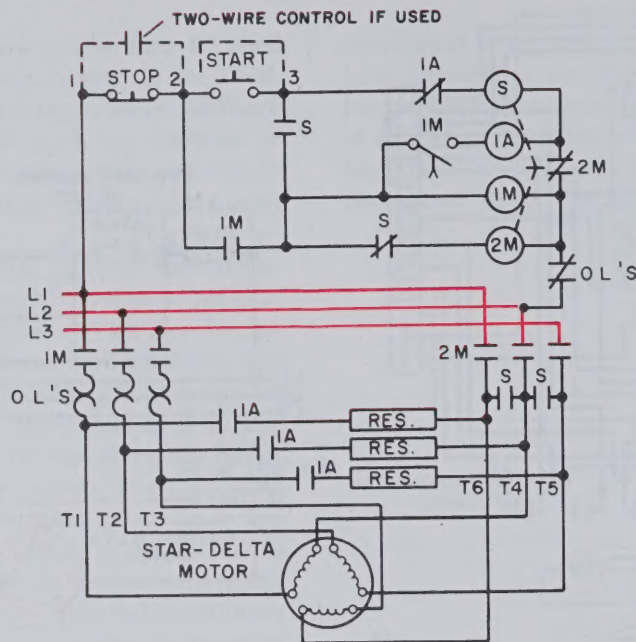


FIG. 27-4(A) Elementary diagram of Sizes 1, 2, 3, 4, 5, and 6 star-delta starters with transition starting

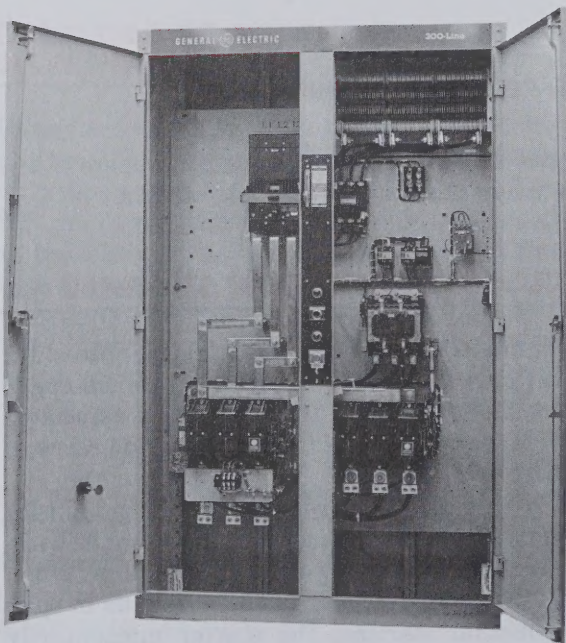


FIG. 27-4(B) Size 6 combination Wye-Delta (Closed transition) Motor Starter (Courtesy of General Electric)

in many cases, some installations may require closed transition starting to prevent power line disturbances. Closed transition starting is achieved by adding a three-pole contactor and three resistors to the starter circuit. The connections are made as shown in the closed transition schematic diagram, figure 27-4. The contactor is energized only during the transition from star to delta. It keeps the motor connected to the power source through the resistors during the transition period, figure 27-5. There is a reduction in the incremental current surge which results from the transition. The balance of the operating sequence of the closed transition starter is similar to that of the open transition star-delta motor starter.

A single method of reduced current starting may not achieve the desired results because the motor starting requirements are so involved, the restrictions so stringent, and the needs so conflicting. It may be necessary to use a combination of starting methods before satisfactory performance is realized. For special installations, it may be necessary to design a starting system to fit the particular conditions.

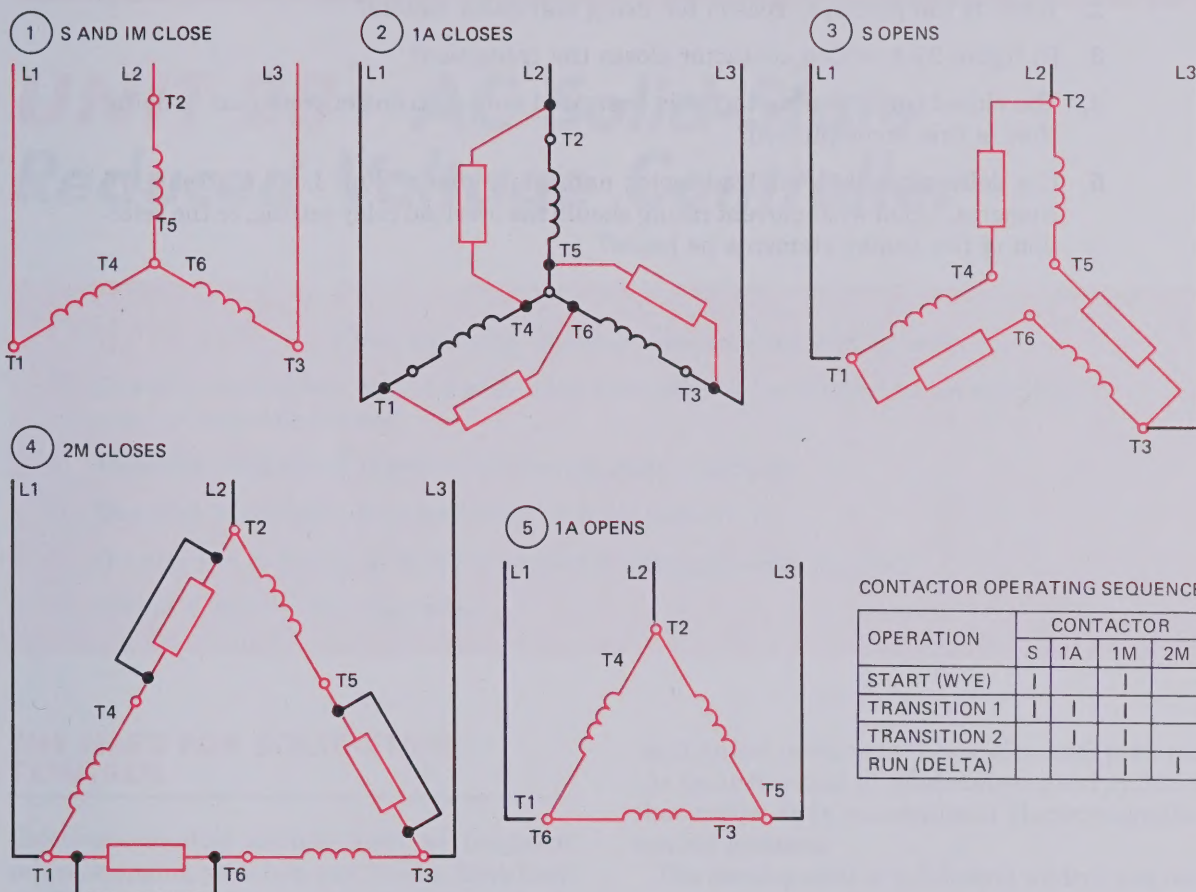
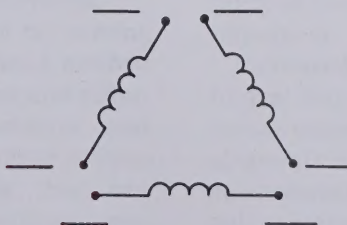


FIG. 27-5 Motor connection and operating sequence for star-delta closed transition starting

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Indicate the correct terminal markings for a star-delta motor on the diagram below.



2. What is the principal reason for using star-delta motors?
3. In figure 27-4, which contactor closes the transition?
4. The closed transition contactor is energized only on transfer from star to delta. How is this accomplished?
5. If a delta-connected, six-lead motor nameplate reads "Full Load Current 170 Amperes," upon what current rating should the overload relay setting, or the selection of the heater elements be based?

UNIT 28 AC Solid-State Reduced Voltage Controller

Objectives

After studying this unit, the student will be able to:

- Describe and draw how a solid-state controller is connected to an existing electromagnetic starter
- Describe additional features of a solid-state controller
- Describe electrical noise and how to help prevent it
- Discuss the function of SCRs in reduced voltage motor starters
- Install a solid-state controller

THE NEED FOR SOLID-STATE CONTROL

Electromechanical devices such as magnetic relays, stepping switches, and timers, have been used for many years to provide decision, or logic circuits for the electrical industry. For example, these devices are used to provide interlocking methods and sequencing control. Their continued wide usage can be expected because they are proven devices, backed by years of engineering experience. Their advantages include: simple construction, flexibility in use, numerous contact combinations, low cost per point switched, easy availability, and ability to carry and break relatively large currents.

Solid-state, or static control, has no moving parts (except accessories). It provides a method for electrically controlling machines and different processes with logic elements and accessories. By means of semiconductor switching devices, such as transistors, they can manipulate electrical signals without any

mechanical movement. Logic elements perform the same function in solid-state control systems that relays do in conventional electromagnetic control systems.

The development of solid-state control was *not* originally intended to replace conventional relays or to render them obsolete. Rather, solid-state switching devices were developed to help meet the more critical demands for reliability, life, and speed for controllers used in automated industries. In automated process lines, not only is it necessary to control individual machines, but also to coordinate material transfer between the machines and to perform many interlocking functions. In such complex circuitry, the reliability of each component becomes increasingly important.

Increased industrial production requires higher duty cycles and creates the need for a device whose life is independent of the number of operations. In addition, many industries (such as chemical, petroleum, and food) impose difficult environmental conditions on electrical

controls which must be overcome. Solid-state control is often the best method to achieve these objectives because these modules are sealed units.

SOLID-STATE REDUCED VOLTAGE MOTOR STARTING

While the details of how a solid-state reduced voltage starter works are complex, the basic principles are easy to grasp. Reduced voltage starting is accomplished by reducing the applied voltage to the motor, which allows the motor to start at a reduced current. The motor then accelerates to full speed at a lower torque level. This technique reduces the high current inrush and the mechanical shock to driven equipment produced by across-the-line motor starting. A solid-state, reduced voltage motor starter uses SCRs (silicon controlled rectifiers) for power control. SCRs are indicated by an arrowhead pointing in the direction of forward current flow, figure 28-1. SCRs block reverse current flow, like diodes. They also block forward current flow



FIG. 28-1(A) Symbol for SCR (silicon controlled rectifier)

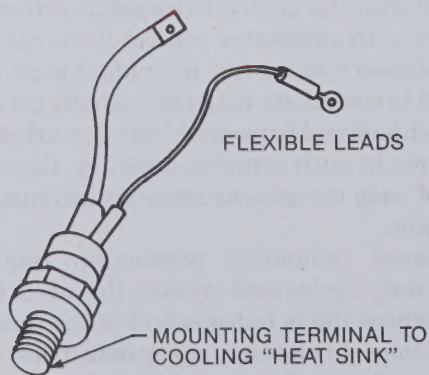


FIG. 28-1(B) Typical power SCR

until they receive a turn-on signal, or gate pulse. Once an SCR is turned on (gated), it does not stop forward current flow. Full-wave control employs two SCRs in each phase by connecting them in inverse parallel. This connection is shown in figure 28-2. In this connection scheme, SCR1 controls the voltage when it is positive in the sine wave. SCR 2 controls the voltage when it is negative. For three-phase motors, the configuration shown in figure 28-3 is used.

Control of current or acceleration time is achieved by gating the SCR at different times within the half-cycle. If the gate pulse is applied early in the half-cycle, the output is high. If the gate pulse is applied late in the half-cycle, only a small part of the waveform is passed through and the output is low. Thus, by controlling the SCR's output voltage, the motor acceleration characteristics can be controlled. These effective waveforms are shown in figure 28-4A. Feedback to the controller is supplied by current transformers in each phase on the line side of the starter, figure 28-4B. Should there be any abnormal changes in the line current through these current transformers, it is detected in the secondary circuit and fed back to a control circuit that adjusts for smooth and timed acceleration. Timed acceleration is also available from a tachometer generator that is attached to the motor shaft. This provides additional feedback to the controller, figure 28-5.

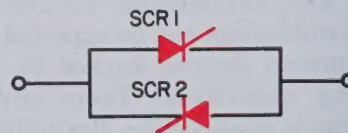


FIG. 28-2 Inverse parallel SCRs per one phase

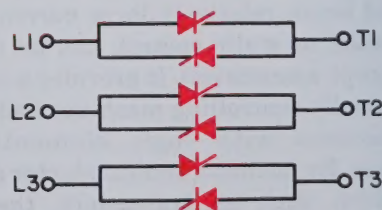


FIG. 28-3 A three-phase SCR connection

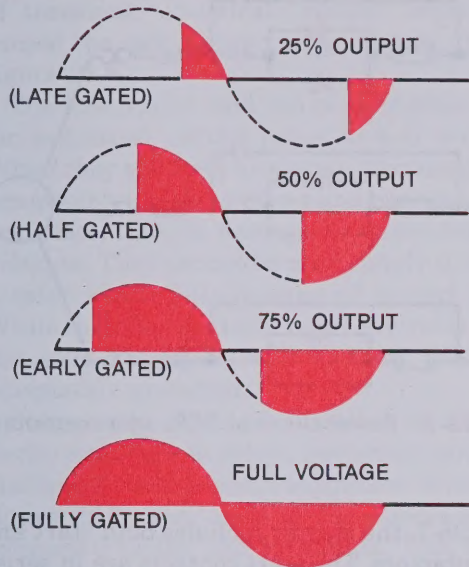


FIG. 28-4(A) Outputs from differently gated SCRs

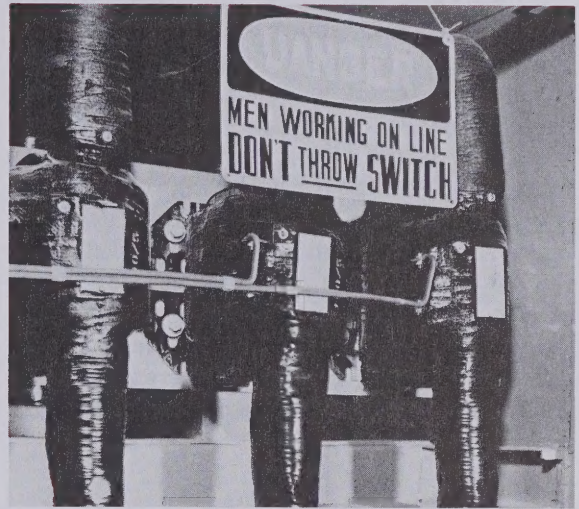


FIG. 28-4(B) Current transformers used for feedback control and metering. The primary is 100 amperes and the secondary is 5 amperes.

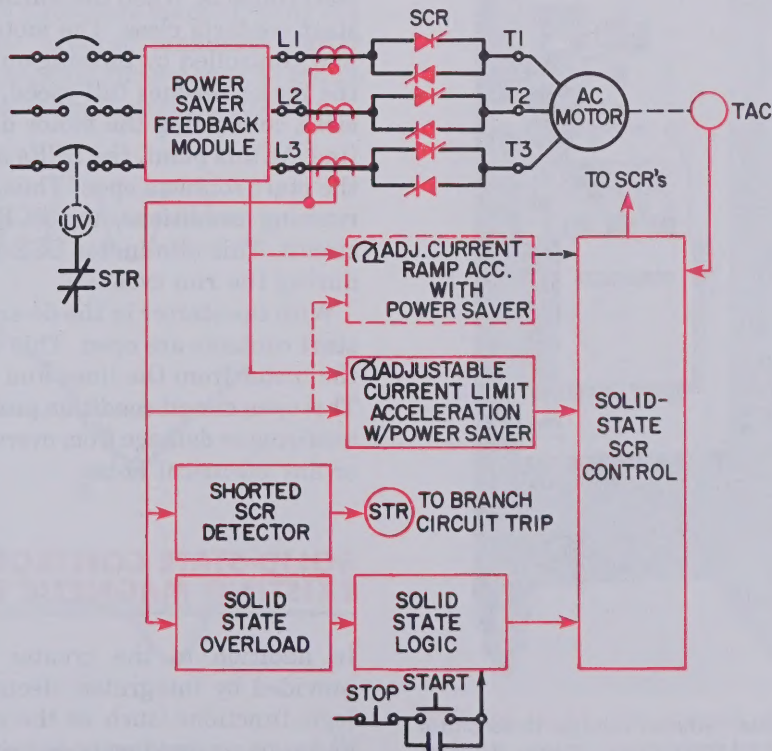


FIG. 28-5 Block diagram of a reduced voltage starter

In addition, solid-state controllers contain solid-state overload relays that monitor both the controller and the motor for overcurrent conditions. Power-saving modules are available that detect idling or low-power periods of operation. The motor terminal voltage is then reduced to minimize electrical losses during these operating conditions. A solid-state, reduced voltage motor starter is shown in figure 28-6. Motor and remote control terminal connections are made at a marked terminal block.

Solid-state starters are available in many different types incorporating different features. As indicated in the elementary diagram in

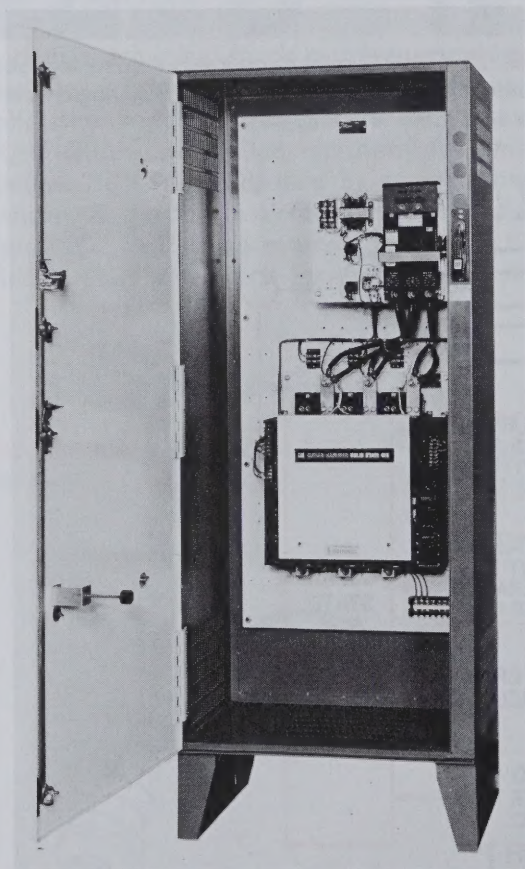


FIG. 28-6 Solid-state, reduced voltage, three-phase starter (Courtesy of EATON Corp., Cutler-Hammer Products)

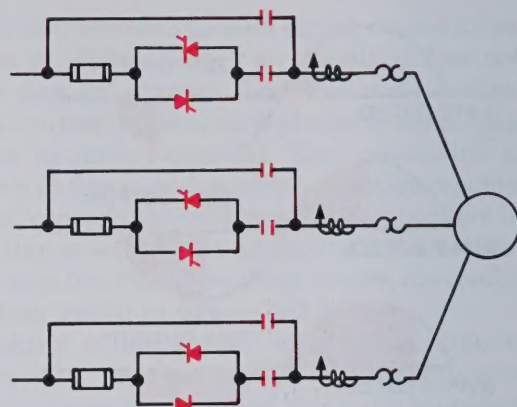


FIG. 28-7 Power circuit of SCR's with contactors

figure 28-7, the starter includes both start and run contactors. The start contacts are in series with the SCR's. The run contacts are in parallel with the series combination of SCR's and the start contacts. When the starter is energized, the start contacts close. The motor acceleration is now controlled by phasing-on the SCR's. When the motor reaches full speed, the run contacts close, connecting the motor directly across the line. At this point, the SCR's are turned off and the start contacts open. Thus, under full speed running conditions, the SCR's are out of the circuit. This eliminates SCR power dissipation during the run cycle.

With the starter in the de-energized state, the start contacts are open. This condition isolates the motor from the lines and the SCR circuits. This open circuit condition protects against SCR misfiring or damage from overvoltage transients, or any electrical noise.

SOLID-STATE CONTROL WITH EXISTING MAGNETIC DEVICES

In addition to the greater noise immunity provided by integrated electronic circuits, the logic functions (such as the relays, contactors, and starters previously described) include additional filtering and buffering to limit the effect

of transient, electrical “spikes” which may exceed the safe voltage noise margin. Refer to figure 28-8.

The integration and use of solid-state relays for industrial control poses several problems. When they are used to operate electromagnetic equipment, replacing relays and contactors, they are susceptible to damage by these transient voltages. They cannot be used simply to replace a relay which fails because of contact arcing. While the relay contacts may have reduced life, the solid-state relay will have no life unless adequately protected.

Surge suppressors are installed on magnetic device coils, such as relays, contactors, and motor starters. A voltage surge suppressor is shown in figure 28-9. The leads of the suppressor are connected to the coil terminals. This further limits voltage noise and overvoltage spikes produced by the starter coil when the coil circuit is opened.

Reduced voltage solid-state starting units can be connected into existing magnetic starter installations for standard three-phase, ac induction motors as shown in figures 28-10A and B.



FIG. 28-9 Voltage surge suppressor (Courtesy Furnas Electric Company)

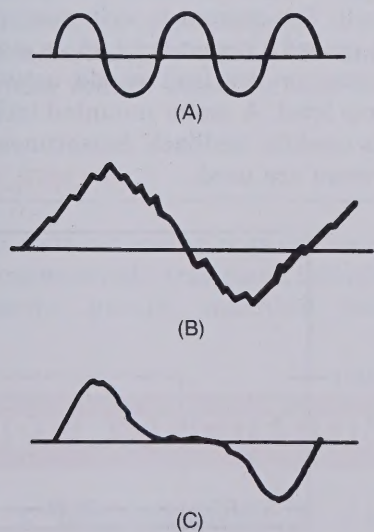


FIG. 28-8 (A) Good computer grade ac power. (B) Objectionable line noise. (C) Bad temporary blackouts.

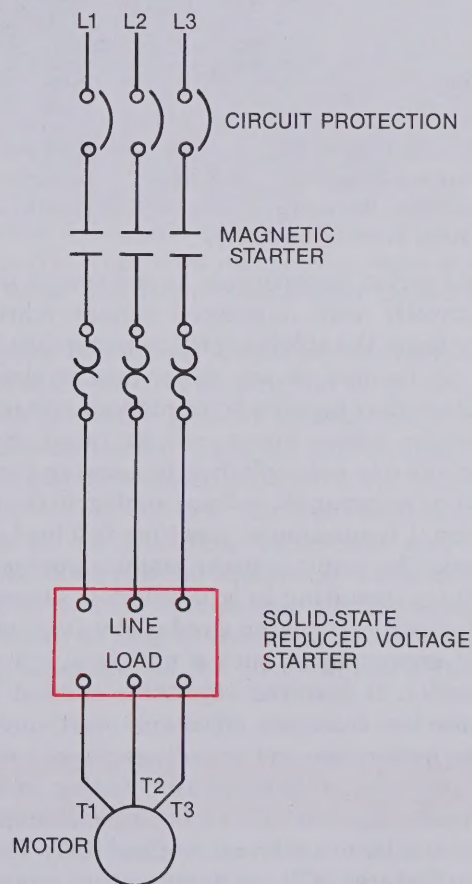


FIG. 28-10(A) Power circuit of a solid-state reduced voltage starter connected into an existing motor installation

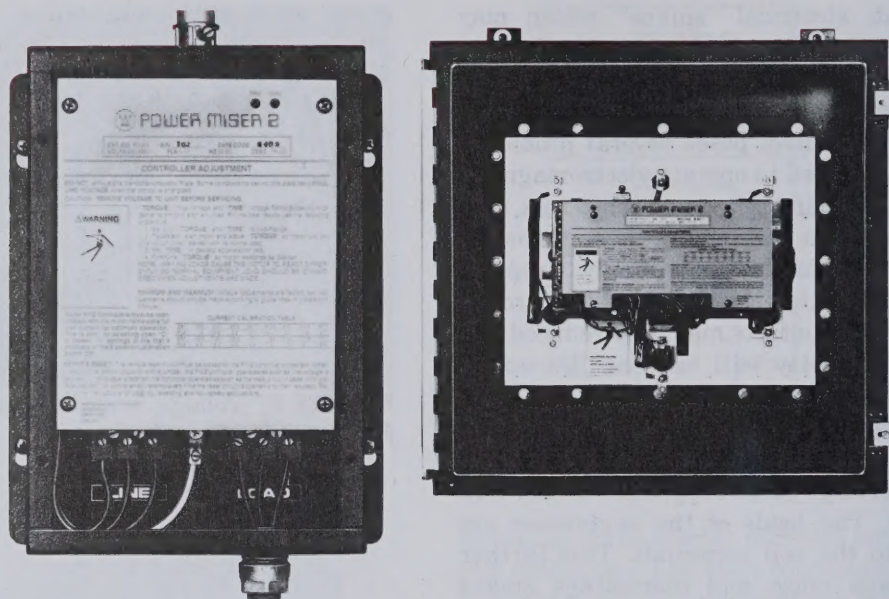


FIG. 28-10(B) This controller senses the motor load and feeds back the information, which is compared to a reference. As a result, the voltage can be continuously changed to reduce the current and voltage under light load conditions. This energy saving feature results in lower power consumption and increased line power factor. (Courtesy of Allen-Bradley Company)

This series incorporates an automatic energy controller with a reduced voltage starter to maximize the efficiency of the motor duty cycle. It can be used on any motor load or electrical system that benefits from reduced voltage soft start or where power can be saved. Energy savings are accomplished by sensing the load and by reducing the voltage applied to the motor when it is running at less than full load conditions. The result is lower motor amperage and voltage (resulting in true kilowatt savings).

In addition to being a reduced voltage starter and energy saver, such a unit is also a motor monitor. It features adjustable current limit, phase loss detection, adjustable start, undervoltage protection, and no voltage phase reversal. It also has a three-phase sensing overload current trip that acts on an inverse time function similar to a thermal overload relay. The unit also features SCR overtemperature protection. Figure 28-11 shows a graph of the adjustable linear timed acceleration of a solid-state starter. This option starts the motor with a linear speed

versus time acceleration. The starting is adjustable, thereby altering the current ramp. Some units may be adjusted for across-the-line starting as well. The current is still monitored so it does not exceed a preset level while starting. A locked rotor or overload would activate this preset trip level. A motor mounted tachometer output is used for feedback. Sometimes current transformers are used.

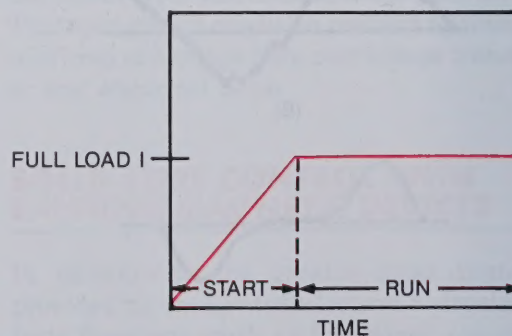


FIG. 28-11 Smooth, stepless acceleration of an induction motor

Nearly all of these functions are illuminated with electronic light-emitting diodes (LEDs). LEDs are similar to pilot lights on push-button control stations. They are color coded and serve as fault indicators and advise of condition status. The color coding of LEDs typically is as follows:

GREEN Control voltage present; or running

AMBER Starting; or energy saver

RED Fault, including:

Shorted SCR; phase loss **GREEN**

SCR overtemperature **AMBER**

Stalled motor **AMBER**

This may be seen in figure 28-12.

ENERGY SAVING

When a motor is lightly loaded or idling, it requires less magnetic flux. An energy-saving option will reduce the magnetic field strength by reducing the voltage to the motor during these periods. When the field is reduced, the motor will draw less current. The energy saving option, including a microcomputer, is activated after the motor is up to speed. It automatically applies more voltage when the load increases.

APPLICATION

The solid-state reduced voltage starter is suited for starting most industrial loads, including fans, compressors, pumps, machine tools and

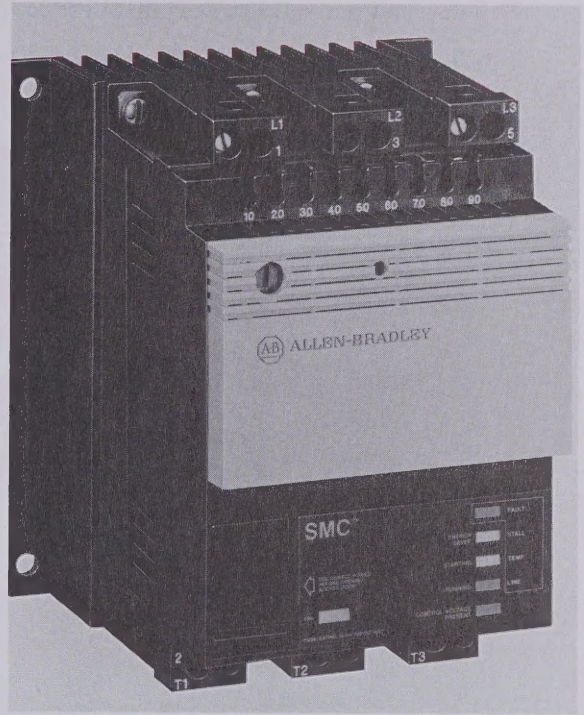


FIG. 28-12 LEDs show the condition status of the motor starter (Courtesy of Allen-Bradley Company)

conveyors. This starter should provide complete control of the starting current and motor torque.

There are some general precautions which should be considered in any application. Because of their greater complexity, failures will be more difficult to find. A more qualified maintenance person or an electronic technician may be required to service the equipment. Installation should be no more difficult than electromagnetic equipment, as long as the installer follows the wiring diagram and the terminal markings.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. List some advantages of solid-state control.
2. What element is the heart of the solid-state starter?
3. How is smooth acceleration achieved with a reduced voltage starter?

4. How are solid-state controllers connected into existing electromagnetic starters?
5. What are some additional features of a solid-state controller not commonly found on an electromagnetic starter?

SECTION SIX

A series of approximately 15 thin, horizontal white lines stacked vertically, serving as a decorative separator between the section title and the main topic.

THREE-PHASE, MULTISPEED CONTROLLERS

UNIT 29 Controllers for Two-speed, Two-winding
(Separate Winding) Motors

UNIT 30 Two-speed, One-winding (Consequent Pole) Motor Controller

UNIT 31 Four-speed, Two-winding (Consequent Pole) Motor Controller

UNIT 29 Controllers for Two-speed, Two-winding (Separate Winding) Motors

Objectives After studying this unit, the student will be able to:

- Identify terminal markings for two-speed, two-winding motors and starters
- Describe the purpose and function of two-speed, two-winding motor starters
- Describe how to obtain different speeds for ac squirrel cage motors
- Connect two-speed, two-winding controllers and motors
- Recommend solutions for troubleshooting these motors and controllers

THE MOTOR

The squirrel cage induction motor is the most widely used industrial motor. It is simple and less expensive than most other motors. Essentially, it is a constant speed motor. Some models, however, are made to operate at several fixed speeds. To do this, the motor manufacturer changes the number of poles for which the stator is wound. The operating principle on which the squirrel cage motor is based calls for a rotor revolving within a stator; this is due to the action of a rotating magnetic field. The speed of the revolving field is determined by the frequency of the alternating current (expressed in hertz) supplied by the alternator and by the number of poles on the stator. The formula defining speed in r/min is:

$$\text{Speed in R/min} = \frac{60 \times \text{Hertz}}{\text{Pairs of Poles}}$$

The metric abbreviation *r/min* (revolutions per minute) refers to the synchronous speed of the motor. At the synchronous speed, the rotor speed equals the rotating magnetic field speed. Practically, however, this synchronous speed is not achieved due to slip, or the lag of the rotor behind the rotating stator field. The phrase *pairs of poles* is used to indicate that motor poles are always in pairs; a motor never has an odd number of poles.

Using the formula for speed, the synchronous speed of a two-pole motor supplied by 60-hertz electrical energy is determined as follows:

$$\frac{60 \times 60}{1} = 3600 \text{ r/min}$$

The motor will run just below the synchronous speed due to slip. The design of the motor will determine the percentage of slip. This value is not the same for all motors.

CONTROLLERS

Line voltage, ac multispeed starters, figure 29-1, are designed to provide control for squirrel cage motors operating on two, three, or four different constant speeds, depending upon their construction. The use of an automatic starter and a control station gives greater operating efficiency.

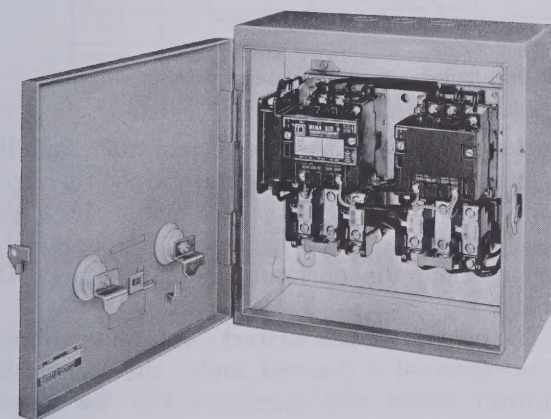


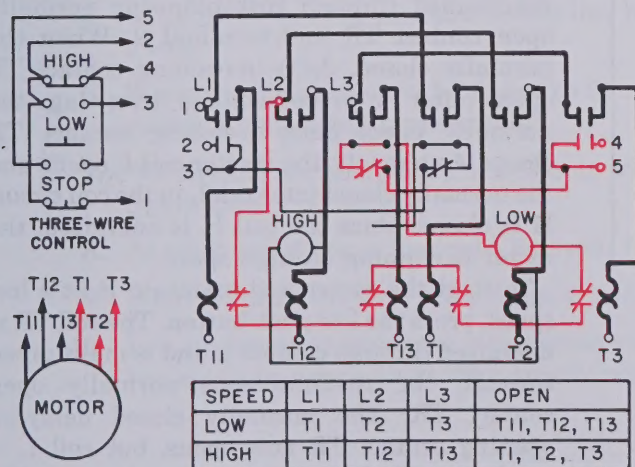
FIG. 29-1 Magnetic controller for two-speed, two-winding (separate winding) motor (Courtesy Square D Co.)

In addition, both the motor and the machine are protected against improper sequencing or rapid speed change. Protection against motor overload at each speed is necessary.

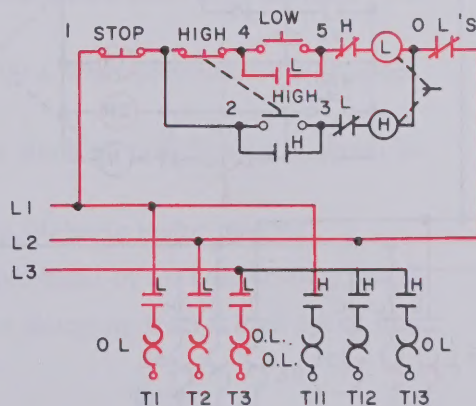
Motors with separate windings have a different winding for each speed required. Although this type of motor is slightly more complicated in construction, and thus more expensive, the controller is relatively simple. Assuming the frequency is constant, two-winding motors will operate on each winding at the speed for which they are wound.

In the control arrangement in (B) of figure 29-2, note that the motor can be started in either speed. However, the stop button must be pressed to transfer from the high speed to the low speed. The starter shown in the figure is provided with a mechanical interlock between the L and H starters. Auxiliary contact interlocks are also provided.

Figure 29-3 illustrates push-button interlocking through the use of combination push buttons. The figure also demonstrates that a transfer can be made to either speed without touching the stop button. However, rapid and continued speed transfers may activate the overload relays. To prevent this, the control scheme



(A)



(B)

FIG. 29-2 Wiring diagram (A) and line diagram (B) for Sizes 2, 3, 4, 5, two-speed, two-winding (separate winding), three-phase motor starters

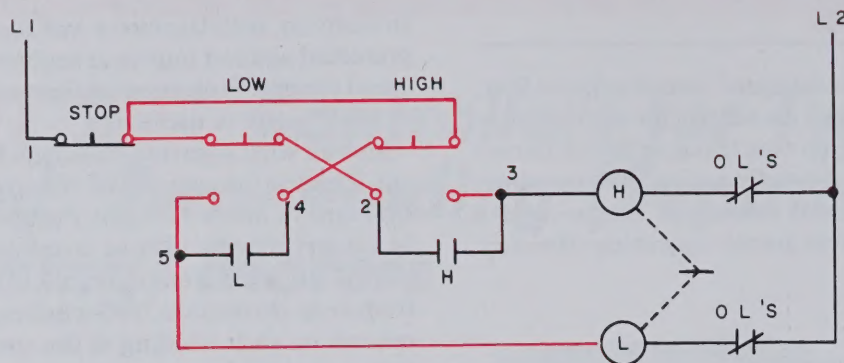


FIG. 29-3 Elementary diagram of pushbutton interlock and transfer to either speed without stopping

can be equipped with time-delay relays that will provide a time lag between the speed changes.

When the motor is operating, the inactive winding must be open circuited. This is done to prevent circulating current due to transformer action between the idle winding and the energized winding.

Figure 29-4 illustrates the function of an accelerating relay circuit from low to high speeds. If high speed is desired, the high-speed

button is depressed. As a result, control relay CR is energized. The circuit is maintained through the normally open contact CR under the high push button located from contact 2 to contact 3. In addition, the normally closed contact CR opens.

The normally open contact CR from terminal 2 to terminal 4 (located under the low push button) closes and energizes the low-speed starter coil L through normally closed contacts TR and H. The motor starts in low speed and normally open auxiliary contact L closes to energize the timing relay TR. The circuit is maintained through instantaneous normally open contact TR and terminal 2. When the normally closed, delay-in-opening contact TR opens after a predetermined time lag, the normally open, delay-in-closing contact TR closes. As a result, the starter coil L opens and the normally closed interlock L in the coil circuit H is closed. Once the coil H is energized, the motor is running on high speed.

To start the motor and maintain it at a low speed, press the low push button. The coil TR is energized through contact L and is maintained through the instantaneous normally open contact TR. The normally closed delay-in-opening contact TR now opens, but coil L is maintained through normally closed contact CR.

To change to high-speed operation, the high push button can be pressed since the normally open, delay-in-closing contact TR is also closed.

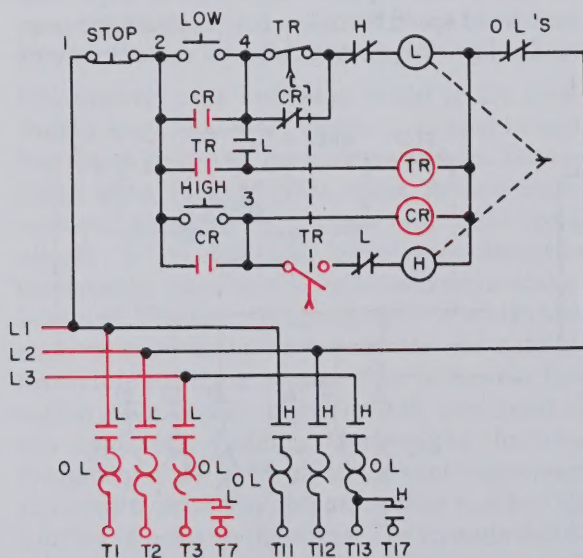


FIG. 29-4 Elementary diagram of starter with an accelerating relay for a two-speed, two-winding, delta-connected, three-phase motor

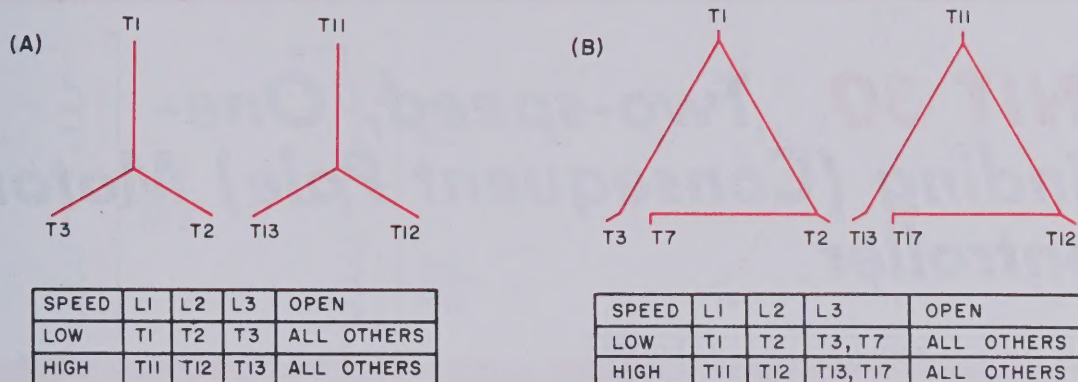


FIG. 29-5 Connections for three-phase, two-speed, two-winding (separate winding) motors (A) star and (B) delta

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Excluding slip, at what speed (r/min) will an eight-pole, 60-hertz, 240-volt motor run?
2. What is meant by the description “separate winding, two-speed motor”?
3. What will happen if an operator makes too many rapid transitions from low to high speed and back on a two-speed motor?
4. Why are there four motor contacts for high and low speeds in figure 29-4?
5. In figure 29-4, what does the broken line between both time-delay contacts (TR) mean?
6. When the high button is depressed in figure 29-4, what prevents the high-speed starter from closing immediately?
7. Which coils are energized immediately when the high push button is closed in figure 29-4?
8. At what speed can a four-pole, 240-volt, 5-hp, 50-hertz motor operate?
9. What is meant by the “compelling action” produced by an accelerating relay?
10. Is it necessary to press the stop button when changing from a high speed to a low speed in figure 29-4? Why or why not?

UNIT 30 Two-speed, One-winding (Consequent Pole) Motor Controller

Objectives After studying this unit, the student will be able to:

- Identify terminal markings for two-speed, one-winding motors and controllers
- Describe the purpose and function of two-speed, one-winding motor starters and motors
- Connect two-speed, one-winding controllers and motors
- Connect a two-speed starter with reversing controls
- Recommend solutions for troubleshooting these motors and controllers

Certain applications require the use of a squirrel cage motor having a winding arranged so that the number of poles can be changed by reversing some of the currents. If the number of poles is doubled, the speed of the motor is cut approximately in half.

The number of poles can be cut in half by changing the polarity of alternate pairs of poles, see figure 30-1. The polarity of half the poles can

be changed by reversing the current in half the coils, figure 30-2.

If a stator field is laid flat (as in figure 30-1) the established stator field must move the rotor twice as far in B as in A and in the same amount of time. As a result, the rotor must travel faster. The fewer the number of poles established in the stator, the greater is the speed in r/min of the rotor.

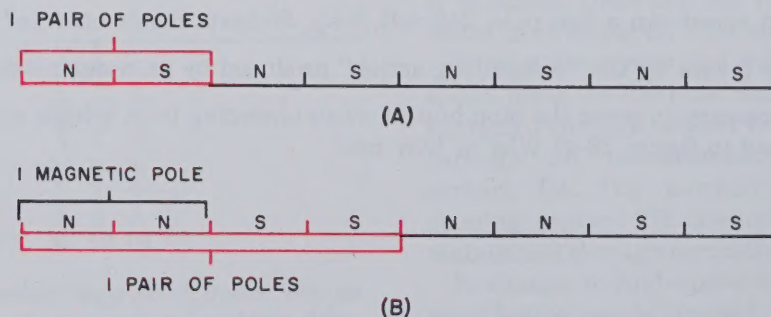


FIG. 30-1 (A) Eight poles for low speed (B) Four poles for high speed

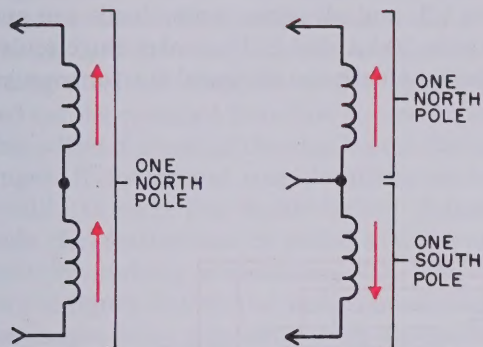


FIG. 30-2 The number of poles is doubled by reversing current through half a phase. Two speeds are obtained by producing twice as many consequent poles for low-speed operation as for high speed.

A three-phase squirrel cage motor can be wound so that six leads are brought out, figure 30-3. By making suitable connections with these leads, the windings can be connected in series delta or parallel wye, figure 30-4. If the winding is such that the series delta connection gives the high speed, then the horsepower rating is the same at both speeds. If the winding is such that the series delta connection gives the low speed and the parallel wye connection gives the high speed, then the torque rating is the same at both speeds.

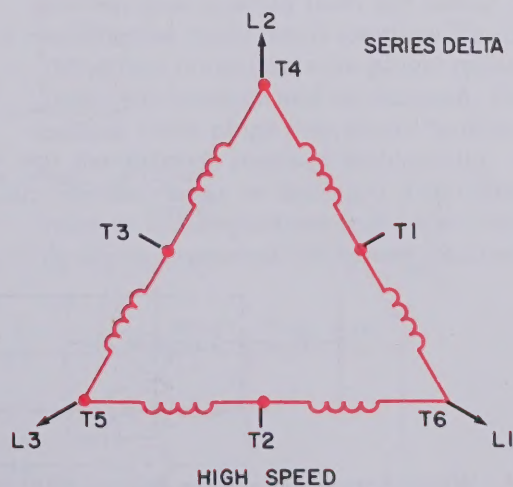
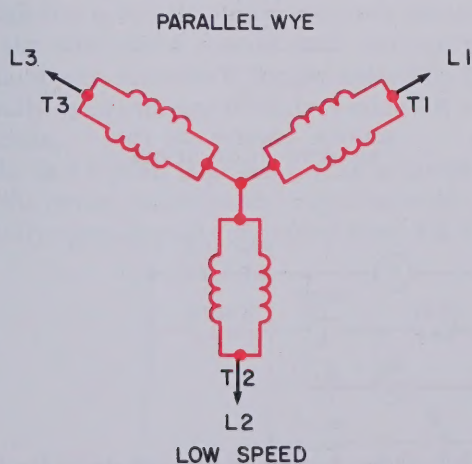
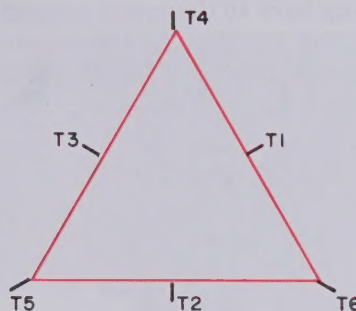


FIG. 30-4 Three-phase, two-speed, one-winding, constant hp motor connections made by motor controller



SPEED	L1	L2	L3	OPEN	TOGETHER
LOW	T1	T2	T3	————	T4, T5, T6
HIGH	T6	T4	T5	ALL OTHERS	————

FIG. 30-3 Connection table for three-phase, two-speed, one-winding, constant horsepower motor

Consequent pole motors have a single winding for two speeds. Extra taps can be brought from the winding to permit reconnection for a different number of stator poles. The speed range is limited to a 1:2 ratio, such as 600-1200 r/min or 900-1800 r/min.

Two-speed, consequent pole motors have one reconnectable winding. However, three-speed, consequent pole motors have two windings, one of which is reconnectable. Four-speed consequent pole motors have two reconnectable windings.

Referring back to the motor connection table in figure 30-3, note that for low speed operation, T1 is connected to L1; T2 to L2; T3 to L3, and T4, T5, and T6 are connected together. For high

speed operation, T6 is connected to L1; T4 to L2; T5 to L3, and all other motor leads are open.

Figure 30-5A and B illustrates the circuit for a Size 1, selective multispeed starter connected

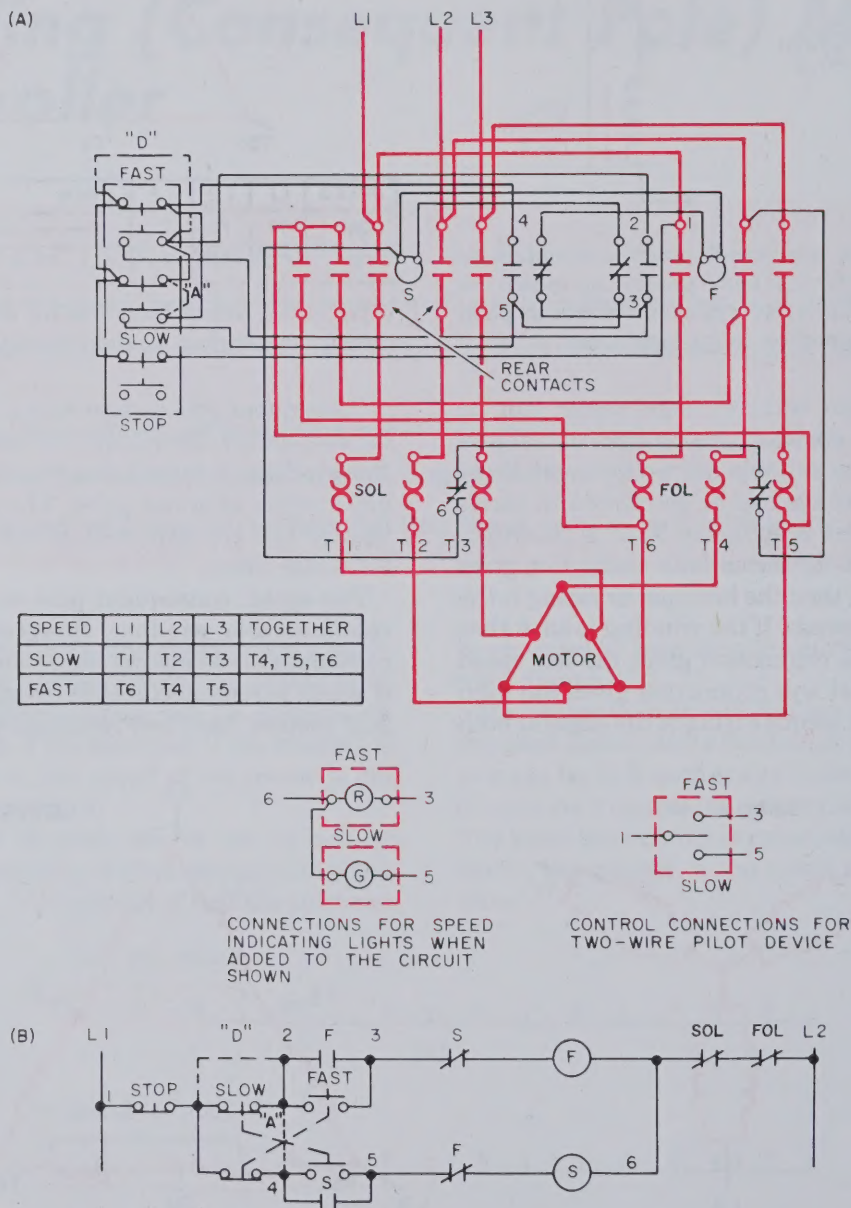


FIG. 30-5 Wiring diagram (A) and line diagram (B) of an ac, full voltage, two-speed magnetic starter for single-winding (reconnectable pole) motors.

for operation with a reconnectable, constant horsepower motor. The control station is a three-element, fast-slow-stop station connected for starting at either the fast or slow speed. The speed can be changed from fast to slow or slow to fast without pressing the stop button between changes. If equipment considerations make it desirable to stop the motor before changing speeds, this feature can be added to the control circuit by making connections “D” and “A”, shown in figure 30-5 by the dashed lines. Adding these jumper wires eliminates push-button interlocking in favor of stopping the motor between speed changes. This feature may be desirable for some applications.

Connections for the addition of indicating lights or a two-wire pilot device instead of the control shown are also given. Figure 30-5C shows a typical full-voltage, magnetic two-speed controller.

A compelling-type control scheme is shown in figure 30-6. These connections mean that the operator must start the motor at the slow speed. This controller can not be switched to the fast speed until after the motor is running.

When the slow button is pressed, the slow-speed starter S and the control relay FR are energized. Once the motor is running, pressing the fast button causes the slow-speed starter to drop out. The high-speed starter is picked up through the normally closed interlock contacts S of the slow-speed starter and through the normally open contacts of control relay FR. The normally open contacts of control relay FR will now close.

If the fast button is pressed in an attempt to start the motor, nothing will happen because the normally open contacts of control relay FR will

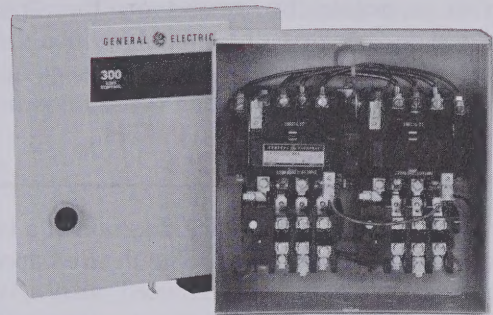


FIG. 30-5(C) Full voltage magnetic two-speed controller, NEMA Size 1, Type 1 enclosure. (Courtesy of General Electric Company, Control Components Operation)

prevent the high-speed starter from energizing. When the fast button is pressed, it breaks a circuit but does not make a circuit. This scheme is another form of sequence starting.

MISTAKEN REVERSAL CAUTION

When multispeed controllers are installed, the electrician should check carefully to insure that the phases between the high- and low-speed windings are not accidentally reversed. Such a phase reverse will also reverse the direction of motor rotation. The driven machine should remain disconnected from the motor until an operational inspection is complete. The upper oil inspection plugs (pressure plugs) in large gear reduction boxes should be removed. Failure to remove these plugs may create broken casings if the motor is reversed accidentally.

Machines can be damaged if the direction of rotation is changed from that for which they are designed. In general, the correct rotational direc-

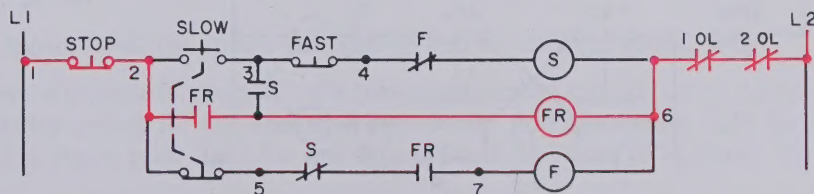


FIG. 30-6 Two-speed control circuit using a compelling relay

tion is indicated by arrows on the driven machine.

TWO-SPEED STARTER WITH REVERSING CONTROLS

Figure 30-7 is an elementary diagram of a two-speed, reversing controller. The desired speed, either high or low, is determined with a two-position selector switch. The direction of rotation is selected with either the forward or reverse

push buttons. When the power contacts (F) or (R) are closed, current is supplied for the "high-low" controls. Assuming that the selector switch is in the high position, contactor L is energized to start the motor in low speed. At the same moment, timing relay coil TR is energized. When the normally closed delay-in-opening contact TR opens after a preset time delay, normally open contact (TR) closes at the same time. This operation drops out contactor L, and the normally closed interlock L energizes contactor H. The motor is now at high speed.

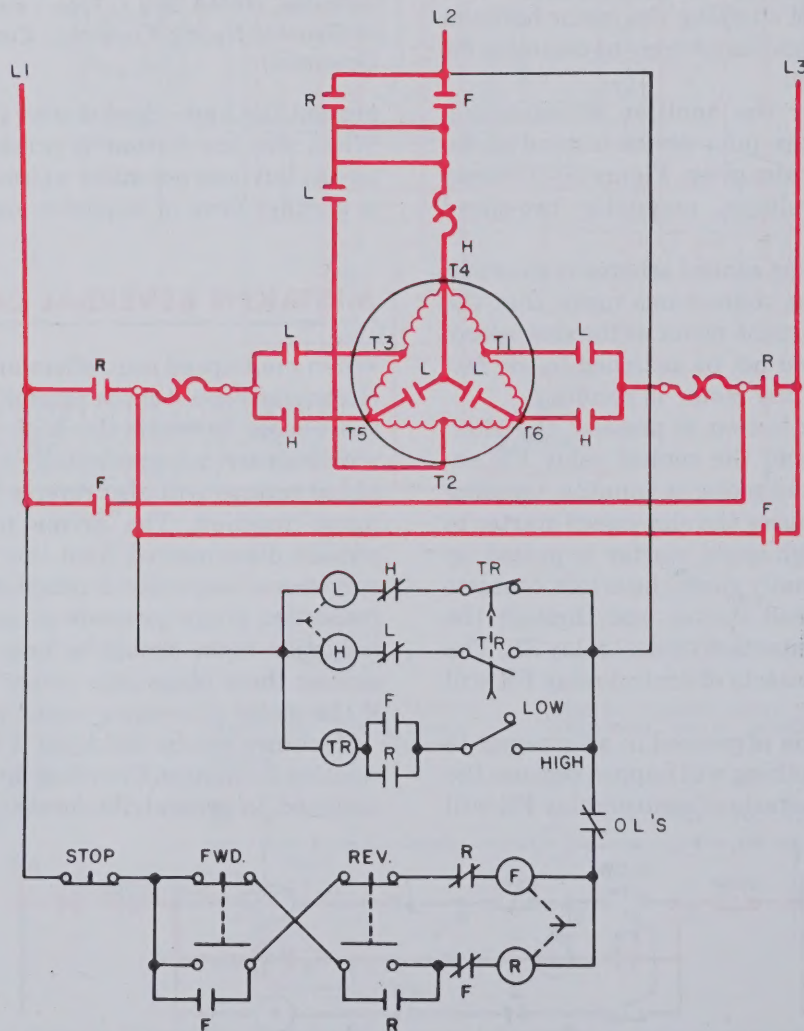


FIG. 30-7 Elementary diagram of a two-speed, reversing controller

The motor may be started in low speed in either direction before it is transferred to high speed. If the low speed is to be maintained, the selector switch is turned to *low* in order to open

the circuit supplying the timing relay coil TR. (This coil would normally transfer the control to high-speed operation.) Typical motor terminal connections are shown in figure 30-8.

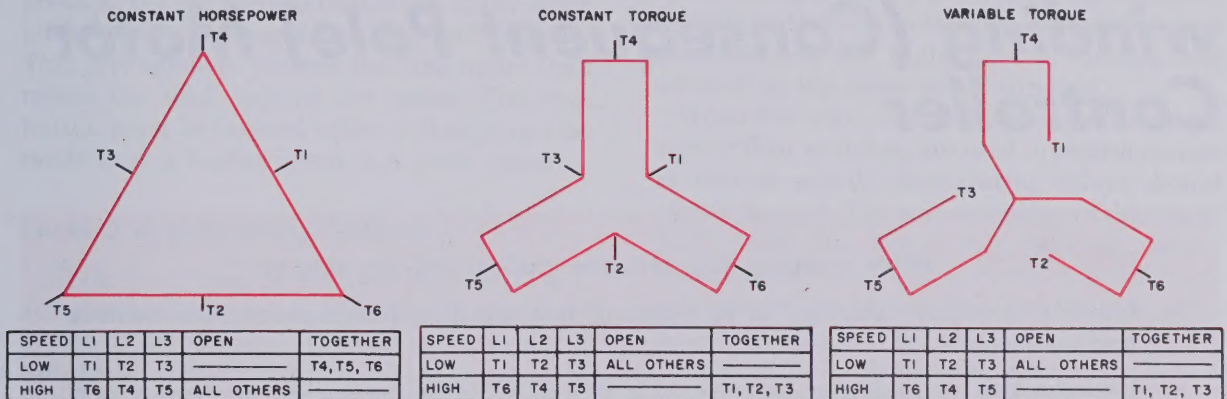


FIG. 30-8 Typical motor connection arrangement for three-phase, two-speed, one-winding motors. These connections conform to NEMA and ASA standards. (All possible arrangements are not shown.)

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. The rotating magnetic field of a two-pole motor travels 360 electrical degrees. How many mechanical degrees does the rotor travel?
2. How can two speeds be obtained from a one-winding motor?
3. What will happen if terminals T5 and T6 in figure 30-3 are interchanged on high speed?
4. Is the motor operating at high speed or low speed when it is connected in series delta? In parallel wye?
5. Describe the operation of the line diagram in figure 30-5(B) by adding jumper "D" only.
6. Describe the operation of figure 30-5(B) by adding jumper wire "A" to the original circuit.
7. In figure 30-6, the motor can not be started in high speed. Why?
8. Draw a schematic diagram of a two-speed control circuit, using a standard duty selector switch for the high and low speeds. Add a red pilot light for fast speed and a green pilot light for low speed. Omit "A" and "D" jumper wires.

UNIT 31 *Four-speed, Two-winding (Consequent Pole) Motor Controller*

Objectives After studying this unit, the student will be able to:

- Identify terminal markings for four-speed, two-winding (consequent pole) motors and controllers
- Describe the purpose and function of four-speed, two-winding motor starters and motors
- Describe the purpose and function of a compelling relay, an accelerating relay, and a decelerating relay
- Connect and troubleshoot four-speed, two-winding controllers and motors

Four-speed, consequent pole, squirrel cage motors have two reconnectable windings and two speeds for each winding.

OPERATIONAL SEQUENCE

Standard starters generally are connected so that the operator can start the motor from rest at any speed, or change from a lower speed to a higher speed. Before a change is made from a higher speed to a lower speed, the stop button must be pressed. This arrangement protects the motor and the driven machinery from the excessive line current and shock that results when a motor running at a high speed is reconnected to run at a lower speed.

Multispeed starters are provided with mechanical and electrical interlocking to avoid the

possibility of short circuiting the line or connecting more than one speed winding at the same time.

COMPELLING RELAYS

Standard starters are not equipped with compelling relays. Such relays insure that the motor starts at the lowest speed or that acceleration is accomplished in a series of steps. (These devices are described in previous units covering multispeed control.) However, when the type of motor used or the characteristics of the load involved makes it necessary to use a particular starting sequence, there are three types of relays available to accomplish the function required: compelling relays, accelerating relays, and decelerating relays.

Form 1 Compelling Relay

When this type of relay is used, the motor must be started at low speed before a higher speed can be selected. The motor can be started only by pressing the low speed push button. If any other push button is pressed, nothing will happen. This arrangement insures that the motor first moves the load only at low speed. The stop button must be pressed before a change can be made from a higher speed to a lower speed.

Form 2 Accelerating Relays

When the starter is equipped with a Form 2 accelerating relay, the final speed is determined by the button pressed. The motor is started at low speed and then is accelerated automatically through successive speed steps until the selected speed is reached. Definite time intervals must elapse between each speed change. Individual timing relays are provided for each interval. Each relay is adjustable. The stop button must be pressed before a change can be made from a higher speed to a lower speed.

Decelerating Relays

This type of relay is similar in action to a Form 2 accelerating relay. The difference is that it controls a stepped *deceleration* from a high speed to a lower speed. Definite time intervals must elapse between each speed change.

Tremendous strains are placed on both the motor and the driven machinery when a change from a higher speed to a lower speed is made and the motor is not allowed to slow down to the desired speed. Such strain is avoided if a definite, adjustable time interval is provided between speeds when the motor is decelerating.

Using three-wire, push-button control and decelerating relays, it is possible to select any speed less than that at which the motor is running by pressing the proper push button. Once this push button is pressed, it de-energizes

the contactor driving the motor at the higher speed and energizes the timing relays. After a preset time period, the timing relays energize the contactor to drive the motor at the lower speed. As successively lower speeds are selected, there is an increase in the elapsed time between disconnecting the higher speed winding and connecting the lower speed winding.

When two-wire control devices, such as pressure or float switches, are used to control motors at various speeds, decelerating relays should always be used. The only exception to this statement is in the event that both the motor manufacturer and the machine manufacturer approve the intended application and agree that decelerating relays are not necessary.

Figure 31-1 is an elementary diagram of a four-speed controller which can be used on a two-winding motor. This circuit is for a standard starter arrangement which is not equipped with compelling relays. (Remember that such relays permit starting only at the lowest speed.) This controller has electrical interlocks which prevent an operator from changing to different speeds without pressing the stop button. A definite time interval must elapse between each speed change on deceleration. The motor should be allowed to slow to the speed desired before a transfer to a lower speed is made.

In the motor connection table in figure 31-1, note that the windings are connected alternately during acceleration. If the first winding is 6 and 12 poles, and the second winding is 4 and 8 poles, then the successive pole connections for acceleration from low speed to high speed are 12, 8, 6, and 4. Figure 31-2 shows common motor connections for four-speed, three-phase, two-winding motors; all have different speeds. Note that the idle winding remains open circuited on given speeds. In this way an unnecessary electrical load is not imposed on the energized winding. This load would result from transformer action which creates circulating currents in the secondary, idle winding.

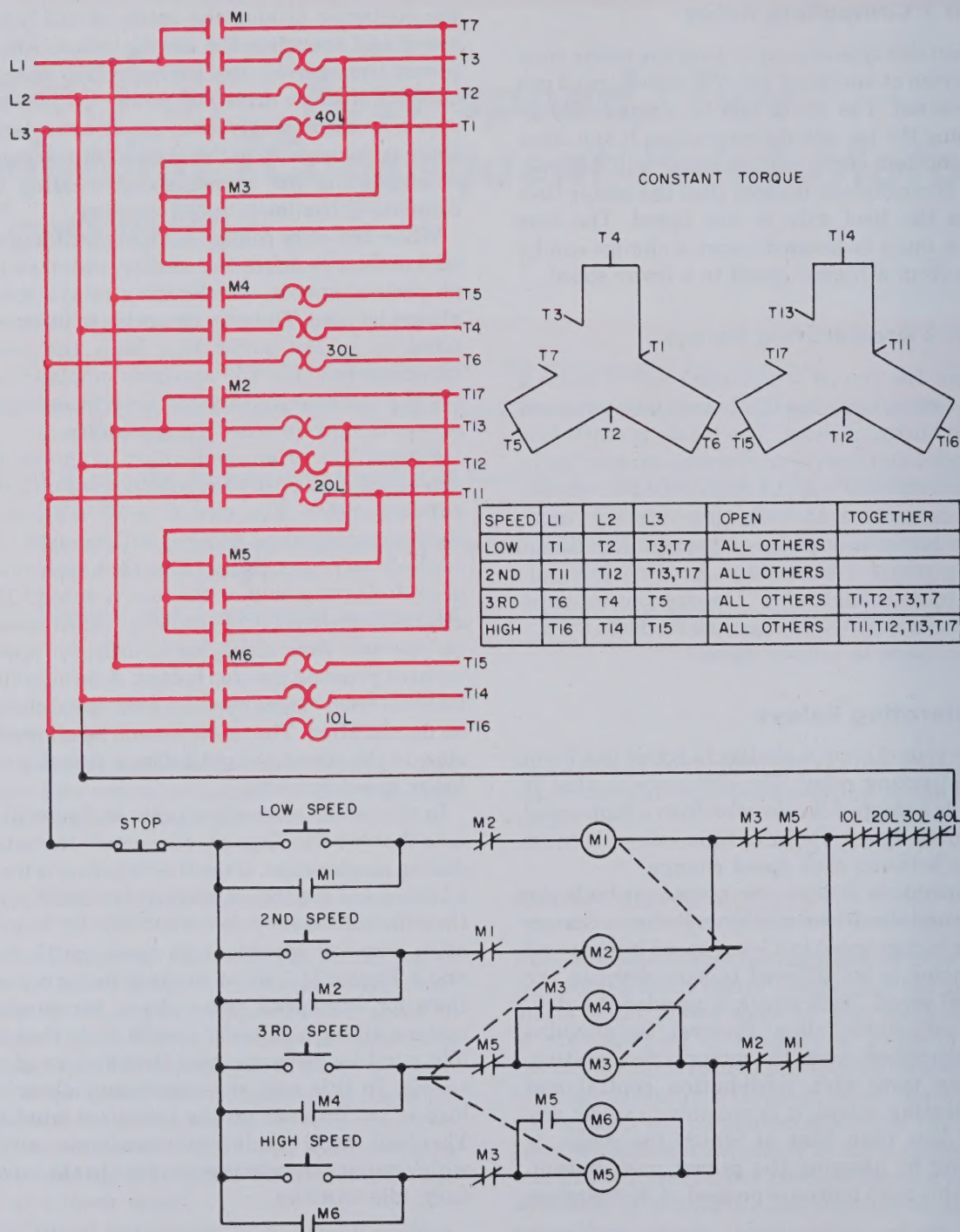
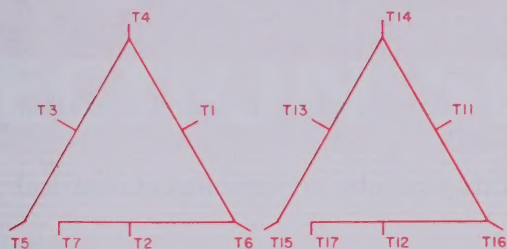


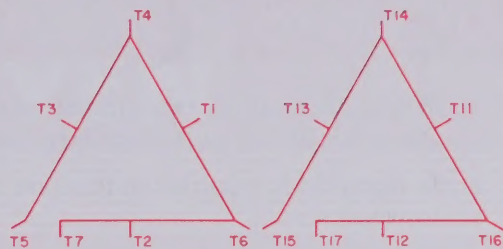
FIG. 31-1 Elementary diagram of a four-speed, two-winding controller

(A) CONSTANT HORSEPOWER



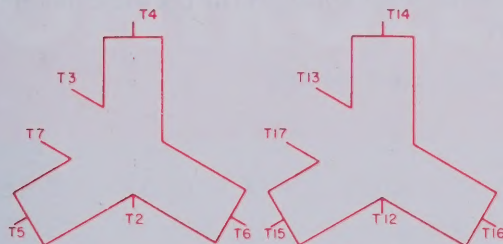
SPEED	L1	L2	L3	OPEN	TOGETHER
LOW	T1	T2	T3	ALL OTHERS	T4, T5, T6, T7
2ND	T6	T4	T5, T7	ALL OTHERS	_____
3RD	T11	T12	T13	ALL OTHERS	T14, T15, T16, T17
HIGH	T16	T14	T15, T17	ALL OTHERS	_____

(B) CONSTANT HORSEPOWER



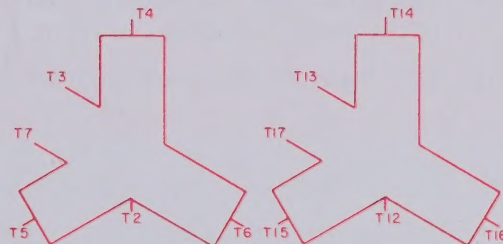
SPEED	L1	L2	L3	OPEN	TOGETHER
LOW	T1	T2	T3	ALL OTHERS	T4, T5, T6, T7
2ND	T11	T12	T13	ALL OTHERS	T14, T15, T16, T17
3RD	T6	T4	T5, T7	ALL OTHERS	_____
HIGH	T16	T14	T15, T17	ALL OTHERS	_____

(C) CONSTANT TORQUE



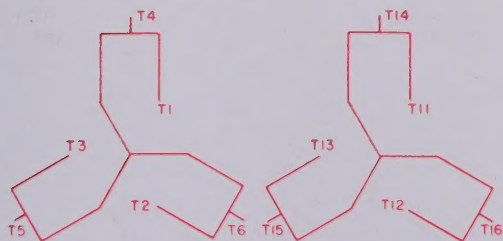
SPEED	L1	L2	L3	OPEN	TOGETHER
LOW	T1	T2	T3, T7	ALL OTHERS	_____
2ND	T6	T4	T5	ALL OTHERS	T1, T2, T3, T7
3RD	T11	T12	T13, T17	ALL OTHERS	_____
HIGH	T16	T14	T15	ALL OTHERS	T11, T12, T13, T17

(D) CONSTANT TORQUE



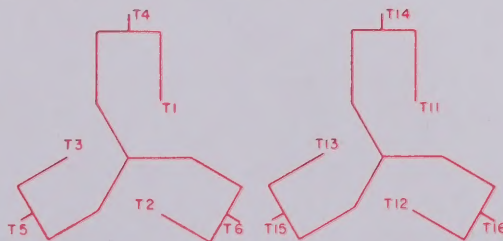
SPEED	L1	L2	L3	OPEN	TOGETHER
LOW	T1	T2	T3, T7	ALL OTHERS	_____
2ND	T11	T12	T13, T17	ALL OTHERS	_____
3RD	T6	T4	T5	ALL OTHERS	T1, T2, T3, T7
HIGH	T16	T14	T15	ALL OTHERS	T11, T12, T13, T17

(E) VARIABLE TORQUE



SPEED	L1	L2	L3	OPEN	TOGETHER
LOW	T1	T2	T3	ALL OTHERS	_____
2ND	T6	T4	T5	ALL OTHERS	T1, T2, T3
3RD	T11	T12	T13	ALL OTHERS	_____
HIGH	T16	T14	T15	ALL OTHERS	T11, T12, T13

(F) VARIABLE TORQUE



SPEED	L1	L2	L3	OPEN	TOGETHER
LOW	T1	T2	T3	ALL OTHERS	_____
2ND	T11	T12	T13	ALL OTHERS	_____
3RD	T6	T4	T5	ALL OTHERS	T1, T2, T3
HIGH	T16	T14	T15	ALL OTHERS	T11, T12, T13

FIG 31-2 Typical arrangements for four-speed, three-phase, two-winding motors

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. When a four-speed, two-winding motor is running, why is it desirable to allow the idle winding to remain open circuited?
2. In figure 31-1, what is the function of this particular arrangement of electrical interlocks?
3. Why are definite time intervals required between each speed change on deceleration?
4. What is the primary reason for using a compelling relay?
5. What is the purpose of an accelerating relay?
6. When is it most important to use decelerating relays for multispeed installations?
7. Why are different motor connections shown for what appears to be the same motor in the various diagrams in figure 31-2?
8. How many windings are required for three-speed motors?

SECTION SEVEN

WOUND ROTOR (SLIP RING) MOTOR CONTROLLERS

- UNIT 32** Wound Rotor Motors and Manual Speed Control
- UNIT 33** Push-button Speed Selection
- UNIT 34** Automatic Acceleration for Wound Rotor Motors
- UNIT 35** Automatic Speed Control for Wound Rotor Motors
- UNIT 36** Solid-State Adjustable Speed Controller
for AC Wound Rotor Motors

UNIT 32 *Wound Rotor Motors and Manual Speed Control*

Objectives After studying this unit, the student will be able to:

- Identify terminal markings for wound rotor (slip ring) motors and controllers
- Describe the purpose and function of manual speed control and wound rotor motor applications
- Explain the difference between two-wire and three-wire control for wound rotor motors
- Connect wound rotor motors with manual speed controllers
- Recommend solutions to troubleshoot problems with these motors

The ac three-phase wound rotor, or slip ring, induction motor was the first alternating-current motor that successfully provided speed control characteristics. This type of motor was an important factor in successfully adapting alternating current for industrial power applications. Because of their flexibility in specialized applications, wound rotor motors and controls are widely used throughout industry to drive conveyors for moving materials, hoists, grinders, mixers, pumps, variable speed fans, saws, and crushers. Advantages of this type of motor include maximum utilization of driven equipment, better coordination with the overall power system, and reduced wear on mechanical equipment. The wound rotor motor has the added features of high starting torque and low starting current. These features give the motor better operating characteristics for applications requiring a large motor or where the motor must start under load. This motor is especially desirable

where its size is large with respect to the capacity of the transformers or power lines.

The phrase “wound rotor” actually describes the construction of the rotor. In other words, it is wound with wire. When the rotor is installed in a motor, three leads are brought out from the rotor winding to solid conducting slip rings, figure 32-1. Carbon brushes ride on these rings

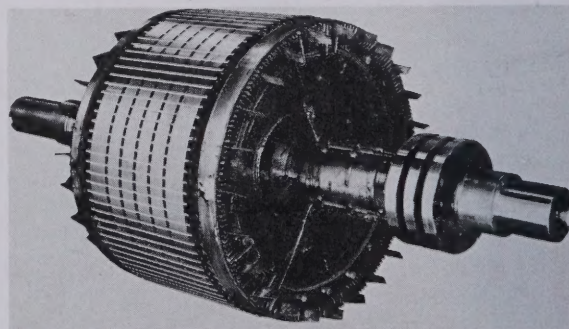


FIG. 32-1 Rotor of an 800 hp, wound rotor induction motor (Courtesy Electric Machinery Mfg. Co.)

and carry the rotor winding circuit out of the motor to a speed controller. Unlike the squirrel cage motor, the induced current can be varied in the wound rotor motor. As a result, the motor speed can also be varied, figure 31-2. (Wound rotor motors have stator windings identical to those used in squirrel cage motors.) The controller varies the resistance (and thus the current), in the rotor circuit to control the acceleration and speed of the rotor once it is operating.

Resistance is introduced into the rotor circuit when the motor is started or when it is operating at slow speed. As the external resistance is eliminated by the controller, the motor accelerates.

Generally wound rotor motors under load are not suitably started with the rings shunted. If such a motor is started in this manner, the rotor resistance is so low that starting currents are too high to be acceptable. In addition, the starting torque is less than if suitable resistors are inserted in the slip-ring circuit. By inserting resistance in the ring circuit, starting currents are decreased and starting torque is increased.

Motors for school and classroom use are provided with one stator and several interchangeable rotors. These rotors can be used with the *same* stator and bearing end brackets. The selection of available rotors includes the following types: *squirrel cage*, *wound*, and *synchronous*.

A control for a wound rotor motor consists of two separate elements: (1) a means of connecting the primary or stator winding to the power lines, and (2) a mechanism for controlling the current in the secondary or rotor circuit. For this reason, wound rotor motor controllers are sometimes called *secondary resistor starters*.

Secondary resistor starters and *speed regulators* have a sliding contact (faceplate) design. This regulator has stationary contacts connected into the resistor circuit. Movable contacts slide over the stationary contacts (from left to right) and cut out of the rotor circuit successive steps of resistance. As a result, there is an increase in the speed of the motor. The entire resistance is removed from the rotor circuit when the extreme right position of the stationary contacts is reached. At this point, the motor is operating at normal speed.

Basically, there are two types of manual controllers, *starters* and *regulators*. The resistors used in *starters* are designed for starting duty only. This means that the operating lever must be moved to the full *ON* position. The lever must *not* be left in any intermediate position. The resistors used in *regulators* are designed for continuous duty. As a result, the operating lever in regulators can be left in any speed position.

When wound rotor motors are used as adjustable speed drives, they are operated on a continuous basis with resistance in the rotor

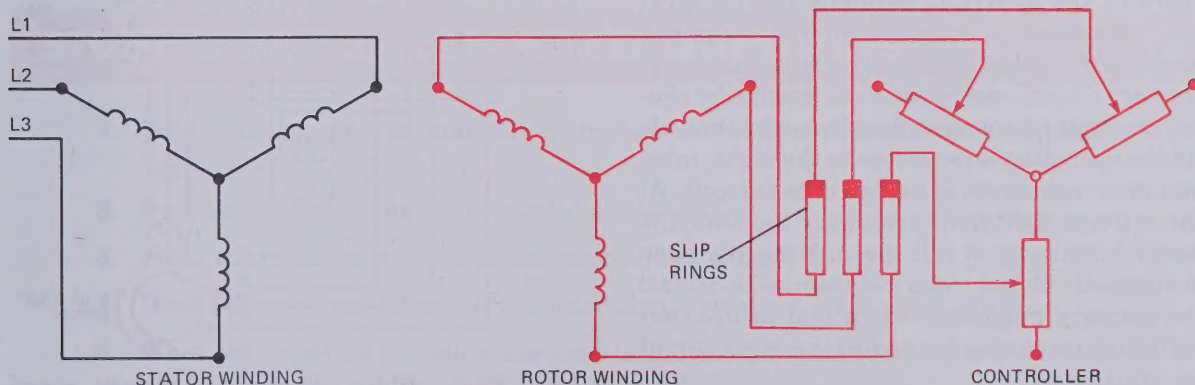


FIG. 32-2 Power circuit: stator, rotor, and controller

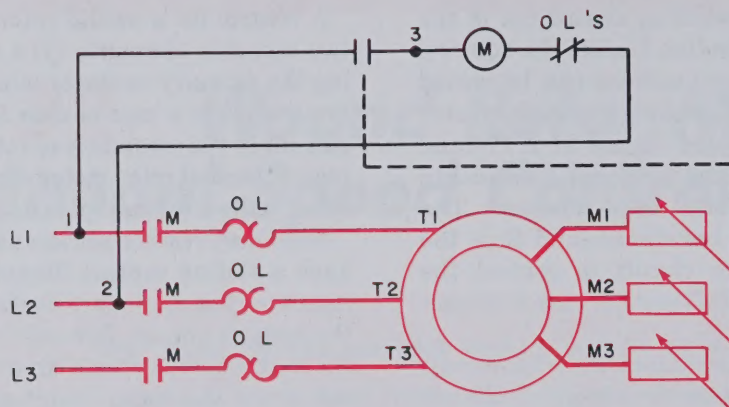


FIG. 32-3 Manual speed regulator interlocked with magnetic starter for control of slip ring motor (two-wire control)

circuit. In this case, the speed regulation of the motor is changed, and the motor operates at less than the full-load speed.

Sliding contact wound rotor starters and regulators do not have a magnetic primary contactor. They control only the secondary (rotor) circuit of the motor. A separate magnetic contactor, automatic starter, or circuit breaker is required for the primary circuit. If a primary magnetic contactor is used, electrical interlocks on the movable contact arm will control the operation of the contactor.

When starting wound rotor motors, the operating lever is moved to the first running position to insert the full value of resistance in the secondary circuit, figure 32-3. This action also operates the electrical normally open contact and completes the circuit to the magnetic primary contactor. This contactor connects the primary circuit, motor stator, to the line by closing the normally open contact (two-wire control). As the operating lever moves to the right, more and more resistance is cut out of the circuit. At the extreme right-hand position of the lever, the motor is running at full speed. Normally open or normally closed electrical interlocks control the primary magnetic switch and insure that sufficient resistance is used in the rotor circuit for starting.

The use of two-wire control (normally open contact) for starting provides low-voltage release.

This means that power to the motor can be interrupted if the line voltage drops to allow value or fails completely. When the voltage returns to its normal value, the motor is restarted automatically. For some applications, this feature is not always desirable.

The use of three-wire control for starting (normally closed control contact), figures 32-4

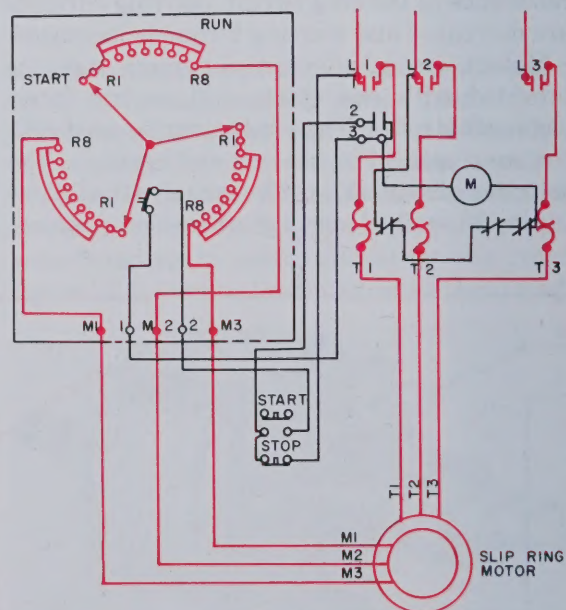


FIG. 32-4 Wiring diagram of manual speed regulator interlocked with magnetic starter for control of slip ring motor (three-wire control)

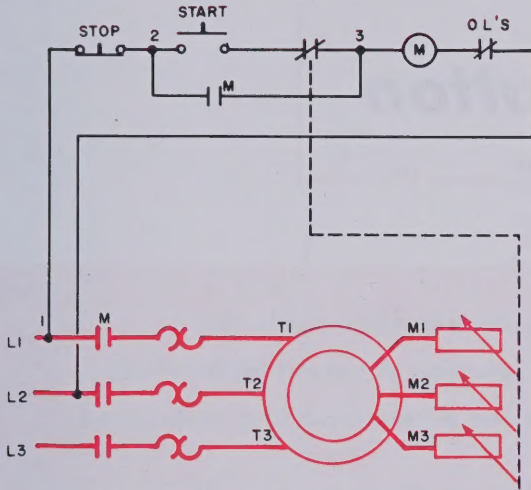


FIG. 32-5 Elementary diagram of figure 32-4

and 32-5, means that low-voltage protection is provided. The motor is disconnected from the line in the event of voltage failure. To restart the motor when the voltage returns to its normal value, the normal starting procedure must be followed. To reverse the motor, any two of the three-phase motor leads may be interchanged.

Drum controllers, figure 32-6, may be used in place of faceplate starters. The drum controller, however, is an independent component; it is sepa-

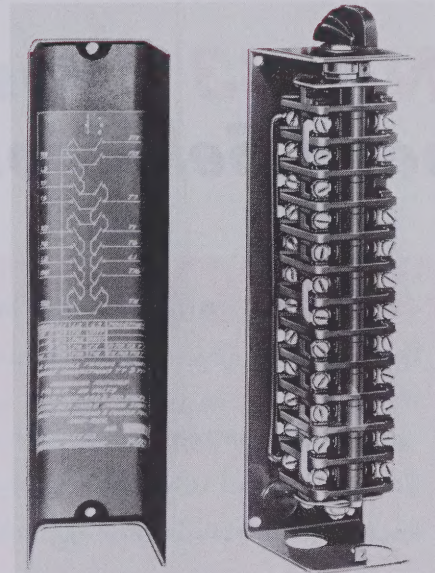


FIG. 32-6 Drum controller (Courtesy of Allen-Bradley Co.)

rate from the resistors and is used for switching or controlling external resistors. As in the faceplate starter, a starting contact controls a line voltage, across-the-line starter. Generally, the electrician must make the connections on the job site.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What characteristic of wound rotor motors led to their wide use for industrial applications? *Variable Speed*
2. By what means is the rotor coupled to the stator? *Carbon Brushes*
3. What other name is given to the wound rotor motor? *Magnetic Slip ring motor*
4. Does increased resistance in the rotor circuit produce low or high speed? *low speed*
5. What two separate elements are used to control a wound rotor motor? *resistance + Voltage linkage*
6. What is the difference between a manual faceplate starter and a manual faceplate regulator?

UNIT 33 *Push-button Speed Selection*

Objectives After studying this unit, the student will be able to:

- Describe the purpose of push-button speed selection of wound rotor motors
- Describe what happens during acceleration and deceleration of a motor used with a push-button speed selector control
- Connect wound rotor motors and push-button speed selector controls
- Recommend troubleshooting solutions for wound rotor problems

Magnetic controllers for wound rotor motors consist of (1) a magnetic starter which connects the primary circuit to the line and (2) one or more accelerating contactors which gradually cut out the resistance in the secondary circuit. (The primary circuit is the stator; the secondary circuit is the rotor.) The number of secondary accelerating contactors depends on the rating of the motor. Enough contactors are used to assure a smooth acceleration and to keep the inrush current within practical limits. The accelerating contactors can be wired for operation by push-button speed selection, figure 33-1.

When the low-speed push button is pressed, the stator is energized by coil M through power contacts M. The motor starts slowly with the full resistance in the rotor secondary circuit. When contactor S is energized by the medium-speed push button, contacts S shunt out part of the total resistance in the rotor circuit. As a result, the rotor speed increases. The speed will continue to increase if the high-speed button is pressed. Because contactor H is energized,

contacts H are closed. All resistance in the secondary circuit of the motor is eliminated or bypassed.

If it is desired to go to medium speed from the high-speed position, the medium push button is pressed. This action de-energizes contactor H and inserts part of the total resistance into the rotor circuit. The rotor speed then decreases. A transfer to low speed can be made in the same manner by pressing the low push button.

This method of push-button speed selection is achieved by a relatively simple, inexpensive control installation. The resistors should have the capacity (power) to operate at any speed.

A disadvantage of this method is that the motor and the driven machine can be accelerated without allowing sufficient time between steps for the rotor to gain its maximum speed for each step of acceleration. The desired time delay can be achieved by adding compelling relays to the circuit to prevent too rapid an acceleration.

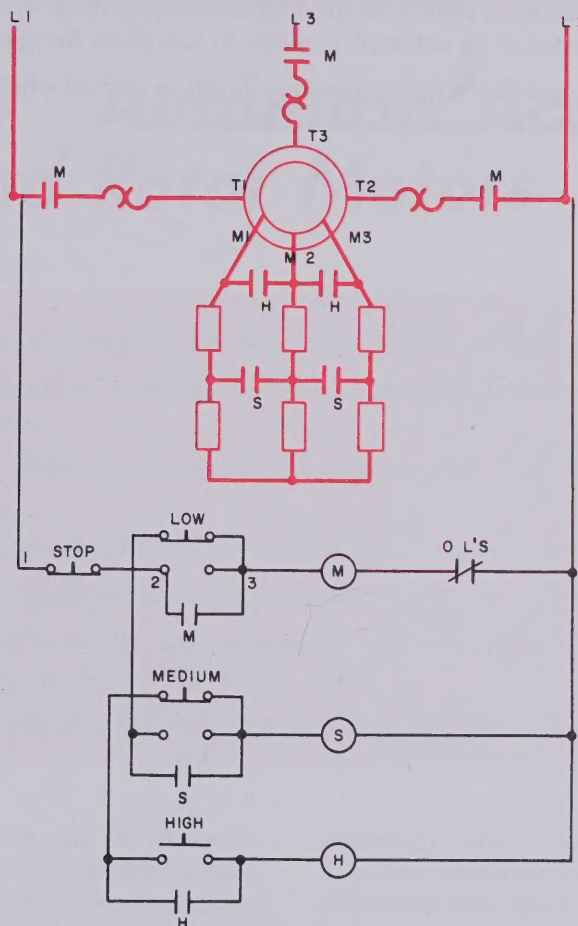


FIG. 33-1 Push-button speed selection for a wound rotor motor

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Can the motor in figure 33-1 be started in medium or high speed? Why?
2. Must the stop button be pressed between speeds on acceleration or deceleration? Why? *No*
3. When the motor is being accelerated, must each push button be closed in succession? Why? *Yes*
4. Is it possible to transfer from a high speed to low speed without pressing the medium push button? Why? *Yes*
5. Do all contactors remain energized when the motor is in high speed? *Yes*

6. Accelerating resistors cannot be used for continuous duty. Why is this true and what may happen if an attempt is made to use them for continuous duty?
7. Draw a line diagram of a three-speed acceleration control which uses compelling timing relays to prevent too rapid an acceleration.

UNIT 34 *Automatic Acceleration for Wound Rotor Motors*

Objectives After studying this unit, the student will be able to:

- State the advantages of using controllers to provide automatic acceleration of wound rotor motors
- Identify terminal markings for automatic acceleration controllers used with wound rotor motors
- Describe the process of automatic acceleration using reversing control
- Describe the process of automatic acceleration using frequency relays
- Connect wound rotor motor and automatic acceleration and reversal controllers using push buttons and limit switches
- Recommend troubleshooting solutions for these problems

Secondary resistor starters used for the automatic acceleration of wound rotor motors consist of (1) an across-the-line starter for connecting the primary circuit to the line and (2) one or more accelerating contactors to shunt out resistance in the secondary circuit as the rotor speed increases. The secondary resistance consists of banks of three uniform wye sections. Each section is to be connected to the slip rings of the motor. The wiring of the accelerating starters and the design of the resistor sections are meant for starting duty only. This type of controller cannot be used for speed regulation. The current inrush on starters with two steps of acceleration is limited by the secondary resistors to a value of approximately 250 percent at the point of the initial acceleration. Resistors on starters with three or more steps of acceleration limit the current inrush to 150 percent at the point of initial acceleration. Resistors for acceleration

generally are designed to withstand one 10-second accelerating period in each 80 seconds of elapsed time, for a duration of one hour without damage.

The operation of accelerating contactors is controlled by a timing device. This device provides timed acceleration in a manner similar to the operation of primary resistor starters. Normally, the timing of the steps of acceleration is controlled by adjustable accelerating relays. When these timing relays are properly adjusted, all starting periods are the same regardless of variations in the starting load. This automatic timing feature eliminates the danger of an improper startup sequence by an inexperienced machine operator.

The primary circuit (stator) in figure 34-1 is energized with the start button. The motor starts with a full value of resistance in the secondary circuit. Coil P actuates the normally open,

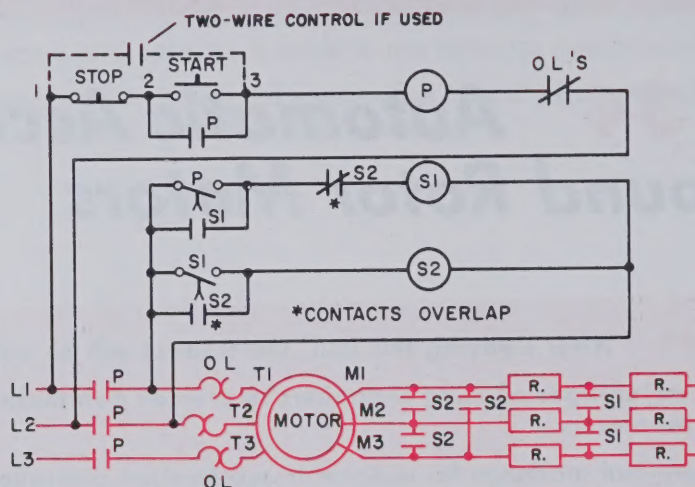


FIG. 34-1 Typical elementary diagram of wound rotor motor starter with three points of acceleration

delay-in-closing contact P. After a preset timing period, contact P closes, energizes contactor S1, and maintains itself through the maintaining contact S1. When contacts S1 in the secondary resistor circuit close, the motor continues to accelerate. After the normally open, delay-in-closing contact S1 times out and closes, contactor S2 is energized and closes the resistor circuit contacts S2. The motor then is accelerated to its maximum speed. The normally closed interlock S2 opens the contactor (S1) circuit. The closing of S2 is assured by staggered, or overlapping, control contacts S2.

AUTOMATIC ACCELERATION WITH REVERSING CONTROL

Automatic acceleration can be obtained in either direction of rotation with the addition to the circuit of reversing contactors and push buttons. The wiring of these devices is shown in figure 34-2.

As described for a squirrel cage motor, a wound rotor motor can be reversed by interchanging any two stator leads.

The motor may be started in either direction of rotation — at low speed with the full secondary resistance inserted in the circuit. For either

direction of rotation, the timing relay TR is energized by the normally open auxiliary contacts (F or R). Coil TR activates the normally open, delay-in-closing contact TR. Coil S is energized when contact TR times out and closes, and removes all of the resistors from the circuit to achieve maximum motor speed. The primary

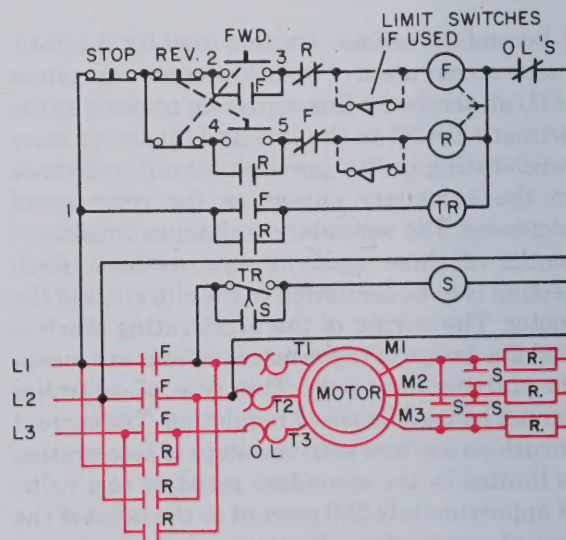


FIG. 34-2 Typical elementary diagram of a starter with two points of acceleration for a reversing wound rotor motor

contactors are interlocked with the push buttons, normally closed interlocking contacts R and F, and the mechanical devices. The connections that occur if a limit switch is used are shown by the dashed lines in figure 34-2. The motor will stop when the limit switch is struck and opened. In this situation, it is necessary to restart the motor in the opposite direction with the push button. As a result, lines 1 and 3 on the primary side will be interchanged. Of course if limit switches are used, the jumper wire must be removed to avoid shunting out the operation of the limit switches.

AUTOMATIC ACCELERATION USING FREQUENCY RELAYS

Definite timers or compensated timers may be used to control the acceleration of wound rotor motors. Definite timers, which usually consist of pneumatic or static relays, are set for the highest load current and remain at the same setting regardless of the load. The operation of a compensated timer is based on the applied load. In other words, the motor will be allowed to accelerate faster for a light load and slower for a heavy load. The frequency relay is one type of compensating timer. This relay uses the principle of electrical resonance in its operation.

When a 60-hertz ac, wound rotor motor is accelerated, the frequency induced in the secondary circuit decreases from 60 hertz at zero speed to 2 or 3 hertz at full speed, see figure 34-3. The voltage between the phases of the secondary circuit decreases in the same proportion from zero speed to full-speed operation. At zero speed, the voltage induced in the rotor is determined by the ratio of the stator and rotor turns. This

action is similar to the operation of a transformer. The frequency, however, is the same as that of the line supply. As the rotor accelerates, the magnetic fields induced in it almost match the rotating magnetic field of the stator. As a result, the number of lines of force cut by the rotor is decreased, causing a decrease in the frequency and voltage of the rotor. The rotor never becomes fully synchronized with the rotating field. This is due to the slip necessary to achieve the relative motion required for induction and the operation of the rotor. The percentage of slip determines the value of the secondary frequency and voltage. If the slip is five percent, then the secondary frequency and voltage are five percent of normal.

Figure 34-4 illustrates a simplified frequency relay system operated by push-button starting. This system has two contactor coils connected in parallel (A and B) and a capacitor connected in series with coil B. A three-step automatic acceleration results from this arrangement. When the motor starts, full voltage is produced across coils A and B causing normally closed contacts A and B to open. The full resistance is connected across the secondary of the motor. As the motor accelerates, the secondary frequency decreases. This means that coil B drops out and contacts B close to decrease the resistance in the rotor circuit, resulting in continued acceleration of the motor. The capacitor depends upon the frequency of an alternating current. As the motor continues to accelerate, coil A drops out and closes contacts A, accelerating the motor further. Because the normally closed contacts are used, the secondary of the motor cannot be shunted out completely. If the secondary could be completely removed from the circuit, the electron flow would take the path of least resistance,

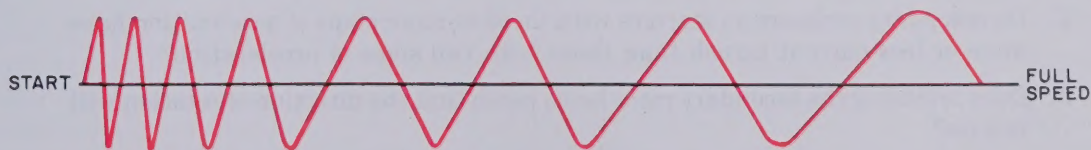


FIG. 34-3 Rotor frequency decreases as the motor approaches full speed.

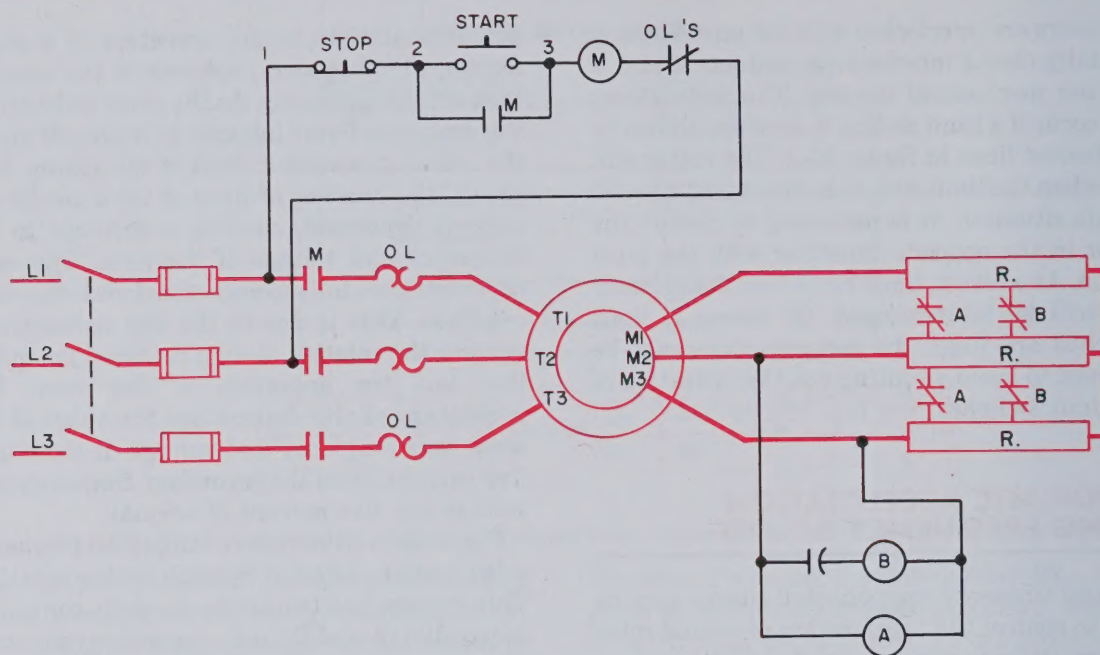


FIG. 34-4 Automatic acceleration of wound rotor motor using simplified frequency relay system

resulting in no energy being delivered to coils A and B upon starting.

The controllers for large crane hoists have a resistance, capacitance, and inductance control circuit network that is independent of the secondary rotor resistors.

Frequency relays have a number of advantages, including:

- (1) positive response
- (2) operating current drops sharply as the frequency drops below the point of resonance
- (3) accuracy is maintained because this type of relay operates in a resonant circuit
- (4) simple circuit
- (5) changes in temperature and variations in line voltage do not affect the relay
- (6) an increase in motor load prolongs the starting time.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Are the secondary resistors connected in three uniform wye or delta sections?
2. Do secondary resistors on starters with three or more steps of acceleration have more or less current inrush than those with two steps of acceleration?
3. Does reversing the secondary rotor leads mean that the direction of rotation will reverse?
4. If one of the secondary resistor contacts (S2) fails in figure 34-1, what will happen?

5. In figure 34-2, how many different interlocking conditions exist? Name them.
6. Referring to figure 34-4, why isn't it possible to remove all of the resistance from the secondary circuit?
7. If frequency relays are used in starting, why is the starting cycle prolonged with an increase in motor load?
8. If there is a locked rotor in the secondary circuit, what will be the value of the frequency?
9. Why is it necessary to remove the jumpers in figure 34-2 if limit switches are used?
10. Referring to figure 34-2, why must the push buttons be used to restart if the limit switches are used?

UNIT 35 *Automatic Speed Control for Wound Rotor Motors*

Objectives After studying this unit, the student will be able to:

- Identify terminal markings for wound rotor motors used with automatic speed controllers
- Describe the purpose and function of automatic speed controllers for wound rotor motors
- Connect wound rotor motors and controllers for automatic speed control
- Recommend solutions for troubleshooting problems with these motors

Automatic speed control of a wound rotor motor can be obtained with the use of pilot devices. It is possible to control acceleration and deceleration, and maintain selected speeds. The line diagram of a typical controller using pilot devices to provide automatic speed control is shown in figure 35-1.

Assume that the wound rotor motor in figure 35-1 is coupled to a fluid pump in a liquid-controlled system. The operation of such a system is described as follows: To maintain the liquid level automatically, the selector switch is placed in the automatic position. As the liquid rises, the master float switch (MFS) closes the circuit to the control switch. As the fluid continues to rise, float switch FS1 energizes control relay CR1. CR1 closes the main starter contacts M to start the motor in slow speed and

energize timing relay T1. If the motor speed is too slow to permit proper fluid delivery, the changing liquid level in the tank eventually closes the third float switch (FS2). CR2 is then energized through the now closed contacts of T1 to operate the first accelerating contactor (1A). In addition, the first bank of resistance is removed from the circuit, and the second time-delay relay (T2) is energized. This process continues until a motor speed is reached that maintains the liquid in the tank at a constant level. If the control selector switch is placed on manual, the float switches are bypassed and the motor must start with all of the resistance inserted in the secondary circuit. The motor must follow the preset timing sequence until all resistance is removed to obtain the maximum operation from the pump.

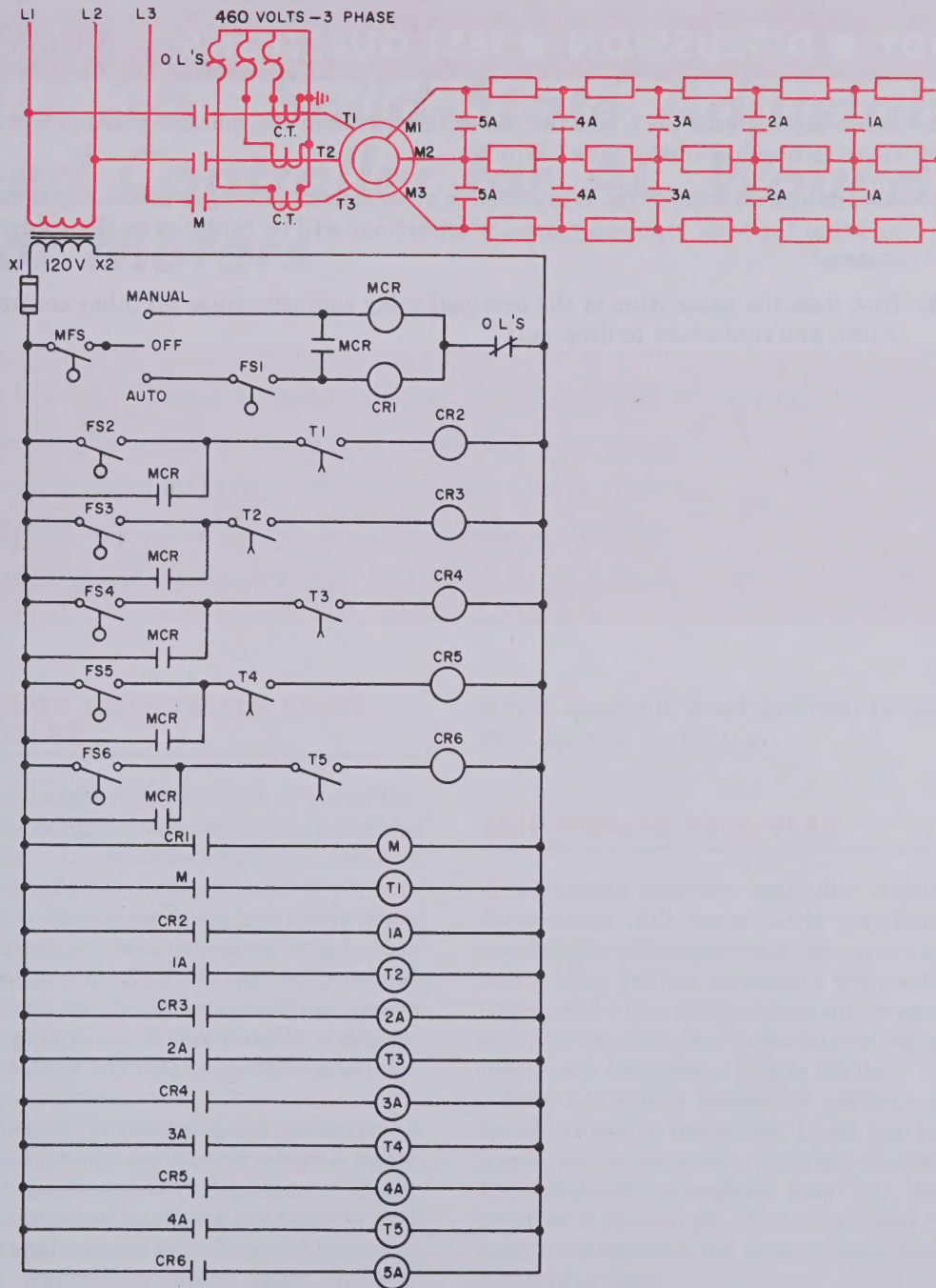


FIG 35-1 Line diagram of wound rotor motor controller using pilot devices to provide automatic speed control. Includes control of acceleration and deceleration and maintenance of selected speeds.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Referring to figure 35-1, can the motor be started in the manual position when there is no fluid in the tank? Why?
2. Assuming that this system is installed in an industrial mixing or processing tank, and that the tank input decreases, what actions will be initiated by the control system?
3. How does the connection of the overload relay contacts cause all other control relays and contactors to drop out?

UNIT 36 *Solid-State Adjustable Speed Controller for AC Wound Rotor Motors*

Objectives After studying this unit, the student will be able to:

- Describe slip power recovery and the method used to achieve it
- Compare the solid-state method of control with resistor methods
- Describe how speed control is accomplished electronically
- Connect power factor correction capacitors into a motor circuit

SOLID-STATE ADJUSTABLE SPEED CONTROLLER

An ideal solid-state adjustable speed controller is a modern, energy-saving method of controlling motor speed. It provides stepless, smooth adjustable speed control of ac wound rotor induction motors. It also recovers slip loss power when the motor runs at less than rated speed. This means that the controller will operate a wound rotor induction motor on less electrical power from the ac power line as compared to resistors, liquid rheostats or any reactor controls, and fluid or magnetic clutches.

The solid-state secondary speed controller is ideally suited for any application where a motor must run at less than its rated maximum speed, such as in water and waste water pumping and various fan applications. Speed control is accomplished by controlling motor rotor current, thereby controlling the motor torque.

Escalating energy costs have made efficiency an important consideration in determining

which adjustable speed controller is best suited for a specific application.

SLIP POWER RECOVERY

A slip power recovery controller consists of a three-phase, full wave diode rectifier which converts the motor secondary voltage to a dc voltage, a filter reactor to smooth the rectification ripple, and a line commutated thyristor/inverter (dc to ac) synchronized to the power line to return motor slip loss power, figure 36-1.

This adjustable controller permits stepless speed control of the motor. Upon reaching full speed, motor secondary shorting thyristors are automatically energized and the thyristor inverter is turned off. This eliminates reactive current returned to the power system during full speed operation.

Electronic circuitry is arranged on plug-in circuit cards, or module, and are located on a plug-in rack. Electronic cards, or modules, are

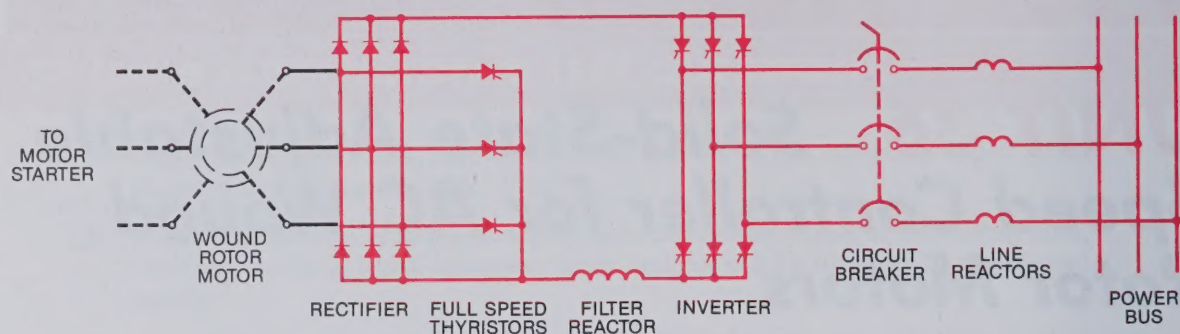


FIG. 36-1 Elementary diagram of a slip power recovery system. Motor starters have been shown.

coated to protect against damage due to moisture and a corrosive environment. Card-edge connectors are generally gold coated to ensure reliable contact between the card and the rack terminals. Cards and modules are also keyed to prevent incorrect insertion. LEDs are provided to indicate the operating status to assist in troubleshooting.

An instantaneous overcurrent circuit detects a fault condition, activates circuitry electronically to clear the fault condition, and allows the controller to resume normal operation. All controller startup adjustments are located on a drive adjust card. Electronic circuits are located on the remaining cards. Ideally, these are replaceable without readjustment of the controller.

POWER FACTOR CORRECTION CAPACITORS

Power factor correction is recommended for all slip power recovery systems. During the operation of a slip power recovery control system, motor secondary current is flowing back into the power line. As the motor speed increases, the current becomes more reactive and if not corrected would result in a very poor power factor. The correct method of connecting the power factor correction capacitors in the circuit is shown in figure 36-2.

Figure 36-3 is a line diagram showing a total operating system. Starting resistors are required for reduced speed range systems only.

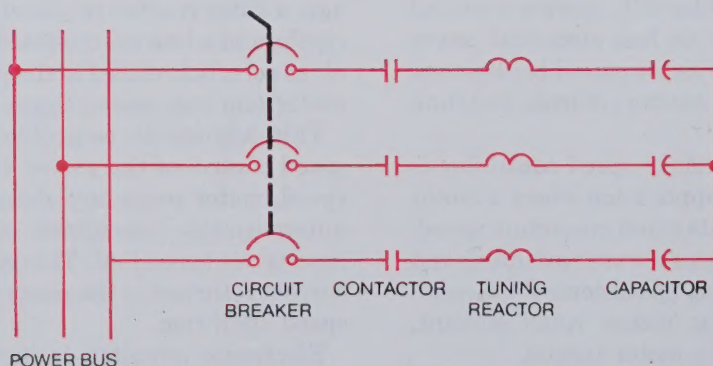


FIG. 36-2 Elementary diagram of power factor correction capacitors

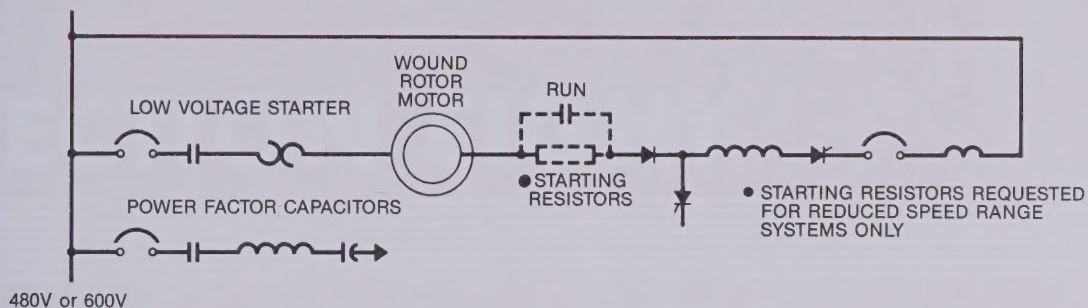


FIG. 36-3 Line diagram of solid-state control with power factor correction

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. If someone told you that the solid-state slip power recovery controller is a perpetual motion machine, what would be your reaction?
2. How do solid-state adjustable speed controllers compare with secondary resistor control?
3. Basically, how is speed control accomplished?
4. Why are capacitors connected into the power circuit?

SECTION EIGHT

SYNCHRONOUS MOTOR CONTROLS

- UNIT 37** Synchronous Motor Operation
- UNIT 38** Push-button Synchronizing
- UNIT 39** Timed Semiautomatic Synchronizing
- UNIT 40** Synchronous Automatic Motor Starter

UNIT 37 Synchronous Motor Operation

Objectives After studying this unit, the student will be able to:

- Describe the operation and applications of a synchronous motor
- Describe lagging and leading power factor and the causes of each
- Describe how the use of a synchronous motor improves the efficiency of an electrical system having a lagging power factor
- Identify a brushless synchronous motor

One of the distinguishing features of the synchronous motor is that it runs without slip at a speed determined by the frequency of the connected power source and the number of poles it contains. This type of motor sets up a rotating field through stator coils energized by alternating current. (This action is similar to the principle of an induction motor.) An independent field is established by a rotor energized by direct current through slip rings mounted on the shaft. The rotor has the same number of coils as the stator. At running speed, these fields (north and south) lock into one another magnetically so that the speed of the rotor is in step with the rotating magnetic field of the stator. In other words, the rotor turns at the synchronous speed. Variations in the connected load do not cause a corresponding change in speed, as they would with the induction motor.

The rotor, figure 37-1, is excited by a source of direct current so that it produces alternate north and south poles. These poles are then attracted by the rotating magnetic field in the stator. The rotor must have the same number of poles as the stator winding. Every rotor pole, north and

south, has an alternate stator pole, south and north, with which it can synchronize.

The rotor has dc field windings to which direct current is supplied through collector rings (slip rings). The current is provided from either an external source or a small dc generator connected to the end of the rotor shaft.

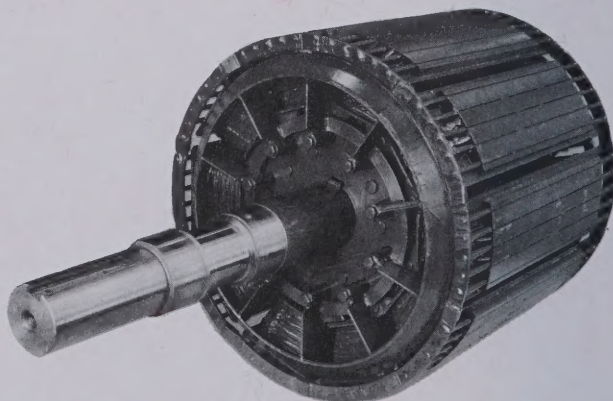


FIG. 37-1 Rotor of 300-hp, 720-r/min synchronous motor (Courtesy of Electric Machinery Mfg. Co.)

The magnetic fields of the rotor poles are locked into step with — and pulled around by — the revolving field of the stator. Assuming that the rotor and stator have the same number of poles, the rotor moves at the stator frequency (in hertz) actually produced by the generator supplying the motor.

Synchronous motors are constructed almost exactly like alternators. They differ only in those features of design that may make the motor better adapted to its particular purpose.

A synchronous motor can not start without help because the dc rotor poles at rest are alternately attracted and repelled by the revolving stator field. Therefore, an induction squirrel cage, or starting, winding is embedded in the pole faces of the rotor. This is called an *armor-tisseur* (ah-more-ti-sir) winding.

This starting winding resembles a squirrel cage winding. The induction effect of the starting winding provides the starting, accelerating, and pull-up torques required. The winding is designed to be used only for starting and for damping oscillations during running. It can not be used like the winding of the conventional squirrel cage motor. It has a relatively small cross-sectional area and will overheat if the motor is used as a squirrel cage induction motor.

The slip is equal to 100 percent at the moment of starting. Thus, when the ac rotating magnetic

field of the stator cuts the rotor windings, which are stationary at startup, the induced voltages produced may be high enough to damage the insulation if precautions are not taken.

If the dc rotor field is either connected as a closed circuit or connected to a discharge resistor during the starting period, the resulting current produces a voltage drop that is opposed to the generated voltage. Thus, the induced voltage at the field terminals is reduced. The squirrel cage winding is used to *start* the synchronous motor in the same way it is used in the squirrel cage induction motor. When the rotor reaches the maximum speed to which it can be accelerated as a squirrel cage motor (about 95 percent or more of the synchronous speed), direct current is applied to the rotor field coils to establish north and south rotor poles. These poles then are attracted by the poles on the stator. The rotor then accelerates until it locks into synchronous motion with the stator field.

Synchronous motors are used for applications involving large, slow-speed machines with steady loads and constant speeds. Such applications include compressors, fans and pumps, many types of crushers and grinders, and pulp, paper, rubber, chemical, flour, and metal rolling mills, figure 37-2.

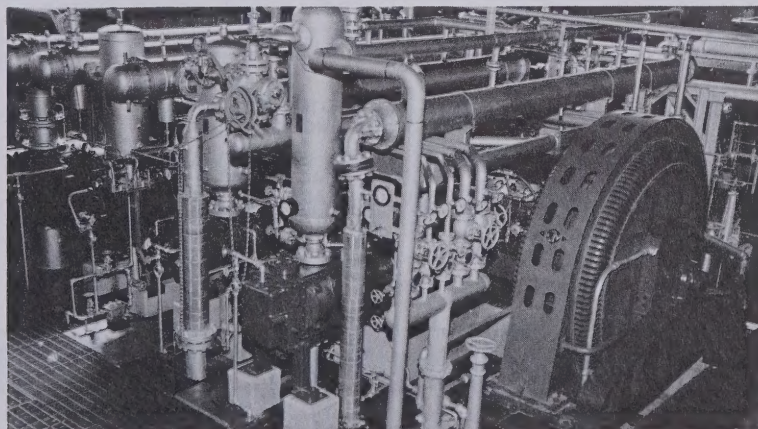


FIG. 37-2 A 2000-hp, 300-r/min synchronous motor driving compressor

POWER FACTOR CORRECTION BY SYNCHRONOUS MOTOR

A synchronous motor converts alternating-current electrical energy into mechanical power. In addition, it also provides power factor correction. It can operate at a leading power factor or at unity. In very rare occasions, it can operate at a lagging power factor.

The power factor is of great concern to industrial users of electricity with respect to energy conservation. Power factor is the ratio of the

actual power, being used in a circuit, expressed in watts or kilowatts, to the power apparently being drawn from the line, expressed in volt-amperes or kilovolt-amperes (kVA). The kVA value is obtained by multiplying a voltmeter reading and an ammeter reading of the same circuit or equipment. Inductance within the circuit will cause the current to lag the voltage.

When the values of the apparent and actual power are equal or in phase, the ratio of these values is 1:1. In other words, when the voltage and amperage are in phase, the ratio of these

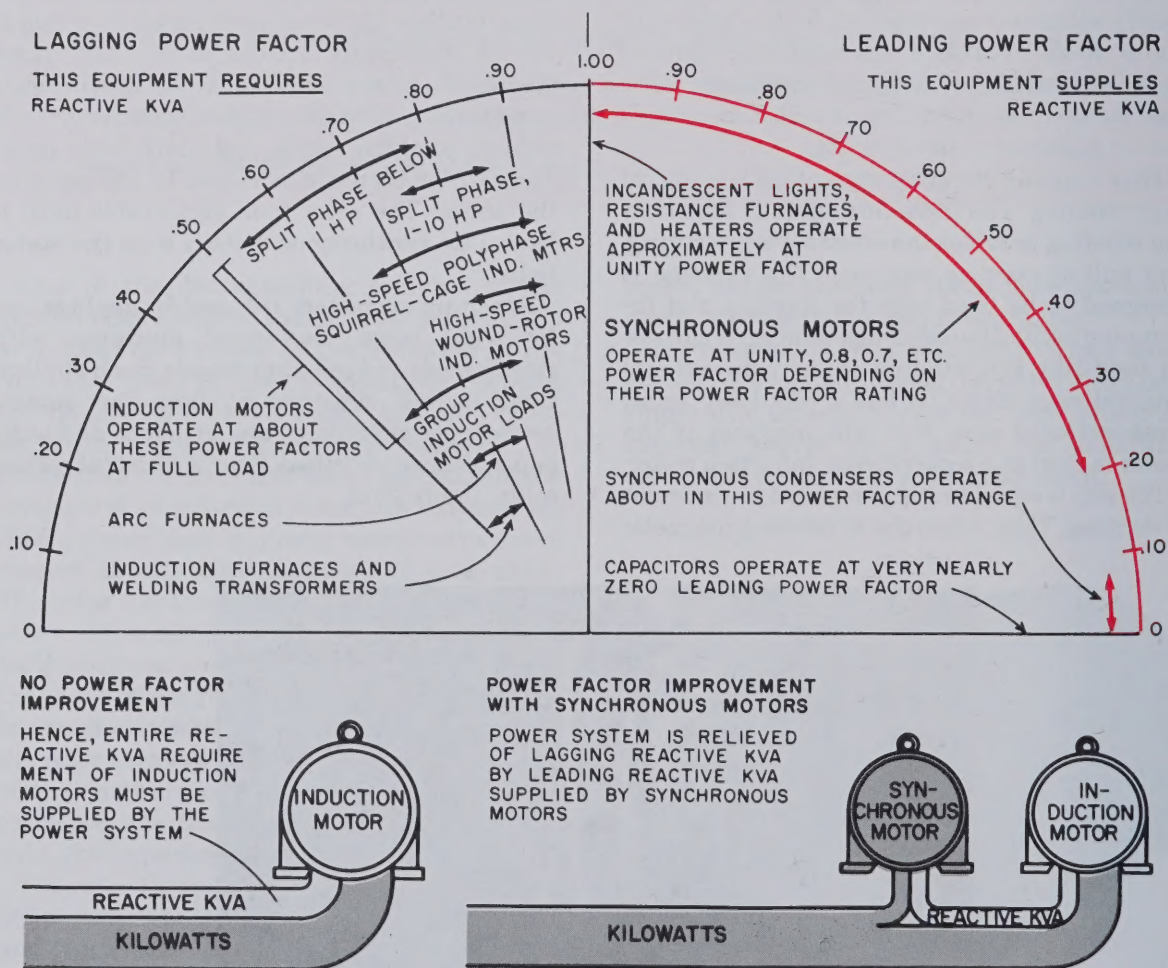


FIG. 37-3 Power factor operation of various devices may be improved through the use of synchronous motors. (Courtesy Electric Machinery Mfg. Co.)

values is 1:1. This is the case of pure resistive loads. The unity power factor value is the highest power factor that can be obtained. The higher the power factor, the greater is the efficiency of the electrical equipment.

Ac loads generally have a lagging power factor. As a result, these loads burden the power system with a large reactive load. Refer to the induction motor in figure 37-3. A synchronous motor should be operated at unity, or at its greatest leading power factor for the most efficient operation. This helps supply reactive power where required in the electrical system. Synchronous motors are operated to offset the low power factor of the other loads on the same electrical system. Therefore, the synchronous motor works to improve the power factor of the electrical system, while turning large, slow-speed machines.

BRUSHLESS SYNCHRONOUS MOTORS

Solid-state technology has brought about the use of brushless synchronous motors. The dc field

excitation for such a motor is provided by a special ac generator mounted on the main motor shaft. The excitation is converted to dc by a rotating rectifier assembly.

The operating characteristics are the same as those of synchronous motors with brushes. However, elimination of the collector rings, brushes, commutator and some control contactors gives the brushless motor several outstanding advantages:

- Brush sparking is eliminated, reducing safety hazards in some areas.
- Field control and excitation are provided by a static system, requiring much less maintenance.
- Field excitation is automatically removed whenever the motor is out of step. Automatic resynchronization can be achieved whenever it is practical.

More is written on this subject in Unit 4.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Why is it necessary that the rotor and stator have an equal number of poles?
2. What is the effect of the starting winding of the synchronous motor on the running speed?
3. What are typical applications of synchronous motors?
4. Explain how the rotor magnetic field is established.
5. A loaded synchronous motor can not operate continuously without dc excitation on the rotor. Why?
6. Why must a discharge resistor be connected in the field circuit for starting?
7. Depending on their power factor ratings, what is the range of the leading power factor at which synchronous motors operate?
8. At what power factor do incandescent light operate?
9. At what power factor do high-speed, wound rotor motors operate?

Select the *best* answer for the following items.

10. The speed of a synchronous motor is fixed by the
 - a. rotor winding
 - b. amortisseur winding
 - c. supply voltage
 - d. frequency of power supply and number of poles
11. Varying the dc voltage to the rotor field changes the
 - a. motor speed
 - b. power factor
 - c. phase excitation
 - d. slip
12. Amortisseur windings are located
 - a. in the stator pole faces
 - b. in the rotor pole faces
 - c. in the controller
 - d. leading the power factor
13. Dc excitation is applied to the
 - a. starting winding
 - b. stator winding
 - c. rotor winding
 - d. amortisseur winding
14. Induction motors and welding transformers require magnetizing current which causes
 - a. lagging power factor
 - b. leading power factor
 - c. unity power factor
 - d. zero power factor
15. A synchronous motor can be used to increase the power factor of an electrical system by
 - a. reducing the speed
 - b. overexciting the stator field
 - c. operating at unity power factor
 - d. applying dc to the stator field

UNIT 38 Push-button Synchronizing

Objectives After studying this unit, the student will be able to:

- Identify terminal markings for a push-button synchronizing controller and synchronous motor
- Describe two functions of synchronous motor control
- Connect synchronous motors and synchronizing controls
- Recommend troubleshooting solutions for synchronous motors and controls
- Describe adjustments that can be made to the circuit of a synchronous motor and control to obtain a power factor of unity or greater
- Synchronize a synchronous motor

There are two basic functions of synchronous motor control in starting:

1. *To start the motor as an induction motor.* The motor can be started using any of the typical induction motor starting schemes. These include connecting the motor across the line or the use of autotransformers, primary resistors, or other devices, depending upon the size of the motor.
2. *To bring the motor up to synchronous speed by exciting the dc field.* The principal difference between synchronous motor control and induction motor control is in the control of the field. Two voltages are needed, ac for the stator and dc for the rotor.

In figure 38-1, the synchronous motor is started as an induction motor by pressing the start button. When the motor reaches its maximum speed, the run push button is closed to energize coil (F) and close the dc excitation

contacts (F). These contacts, in turn, open the field discharge normally closed contact (F) and energize the dc field, F1 and F2 of the motor. The normally closed contact F opens after normally open F contacts close to avoid a high induced voltage in the field. The stator acts like a transformer primary. The dc field circuit receives an induced current (as does a transformer secondary). When the stator is energized, the rotor circuit must be closed at all times. The overlapping normally closed contacts F keep the loading resistor in the circuit. Without it, dangerous high voltages are induced which may rupture the insulation on the rotor windings. The induced current in the rotor-resistor circuit keeps the induced voltage at a tolerable level.

The discharge resistor also prevents arcing at the contacts. In addition, it dissipates the self-induced voltage from the collapsing dc magnetic field of the rotor windings.

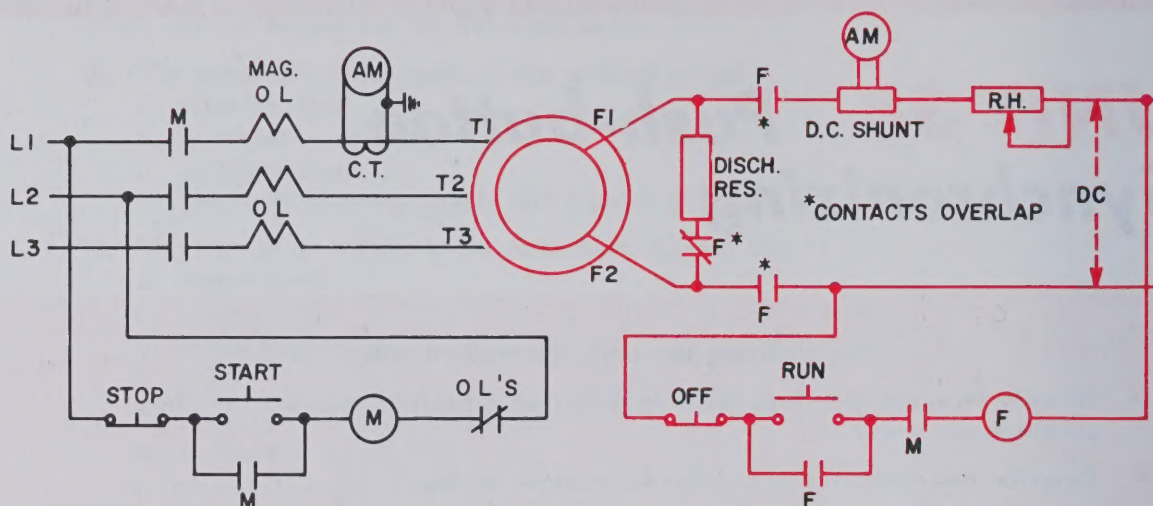


FIG. 38-1 Elementary diagram of push-button synchronizing

Note in figure 38-1 that the normally open contacts M in the F coil circuit prevent the dc field from being energized before the motor is started. These interlocking contacts close only after the ac control is energized. Pushing the stop button on the ac side also opens the dc supply. If the motor does not reach synchronous speed with the first try, the *off* button should be pressed. The run push button can then be re-engaged.

The ammeter and rheostat shown in the dc circuit in figure 38-1 control the excitation current. The unity power factor of the motor can be found by adjusting the rheostat to obtain a minimum reading on the ac ammeter in the stator circuit, figure 38-2.

Adjustments of the circuit may cause field currents, or line currents, in excess of the motor rating. As a result, electrical instruments must be provided to monitor various circuit values. The operator can then prevent equipment stoppage due to overload tripping. The readings of the instruments must not exceed the rated values shown on the motor nameplate.

The excitation current can be applied manually to excite the dc field to bring the motor up to synchronous speed. For this operation, however, it is the operator who must make the

difficult judgment of when the north and south poles of the rotor and stator fields are paired and the motor is ready for synchronous operation. For this reason, the system does not provide automatic motor synchronization. However, it is a comparatively simple and inexpensive method.

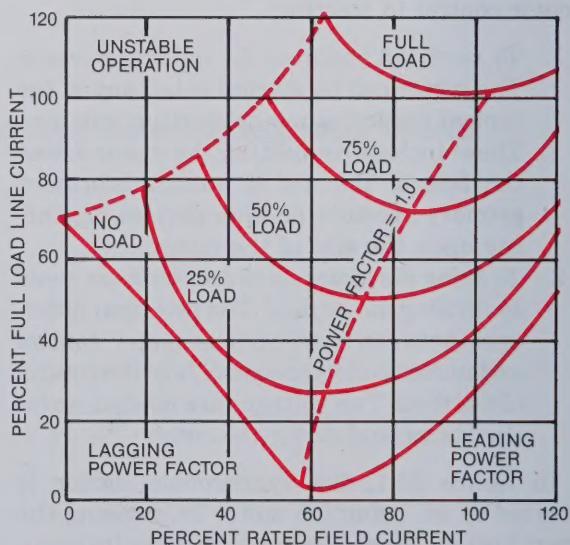


FIG. 38-2 Line current versus field current for motor with a unity power factor

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What are the two basic functions of synchronous motor control?
2. What is the purpose of the interlock (M) in the dc control circuit?
3. If all of the control circuits are ac — and dc is not available — what will be the result of energizing all of the contactor coils?
4. When the rotor and stator fields lock into step, why may the reading of the ac ammeter decrease?
5. Why is manual field application not completely satisfactory?
6. If a synchronizing attempt fails, what procedure should be followed?
7. In figure 36-2, approximately what is the percentage of current drawn from the line when the field current is adjusted to 100 percent of its capacity at full motor load?
8. Why are the ac ammeter and dc meter necessary in the circuit of figure 36-1?
9. Why is the operation of the field contacts (F) overlapped in figure 36-1?

UNIT 39 Timed Semiautomatic Synchronizing

Objectives After studying this unit, the student will be able to:

- Identify terminal markings for a timed semiautomatic controller used with a synchronous motor
- Describe the operation of a timed semiautomatic controller used to bring a motor up to synchronous speed
- Connect synchronous motors and timed semiautomatic controllers
- Recommend ways to troubleshoot these motors and controllers

A synchronous motor may be brought up to synchronous speed with the use of a definite time-delay relay to excite the dc field. This method is shown in the circuit of figure 39-1.

The timing relay coil (TR) is energized with the main starter coil (M). The instantaneous

normally open interlock (M) in the coil circuit (F) is then closed. Both interlock M and the dc contactor coil F must wait for the closing of the delay-in-closing contact TR. After a preset timing period, the rotor has accelerated to the maximum speed possible at this stage. Contact

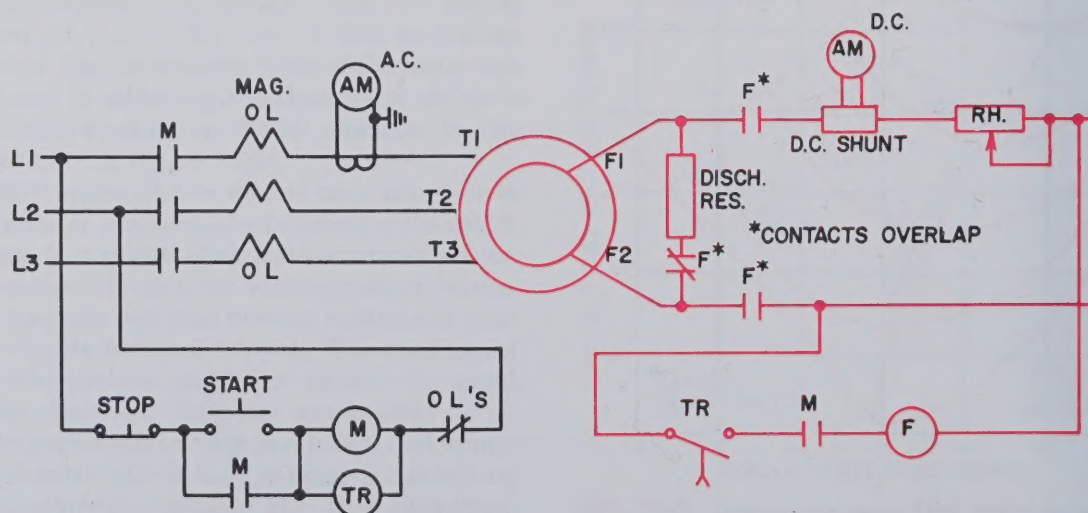


FIG. 39-1 Elementary diagram of a timed, semiautomatic synchronizing installation

TR then closes to accelerate the rotor until it reaches the point where it synchronizes. The timer setting should be adjusted for the maximum time required to accelerate the motor to the point that it can reach the synchronous speed after contact TR closes.

The attempt to synchronize the motor may not be successful. In this case, the stop button is pressed and the starting cycle is repeated. It is

not necessary to bring the rotor to a standstill. Only the timing cycle must be reactivated.

The equipment operator and the electrician should realize that push-button control and timed semiautomatic control of synchronous motors are not guaranteed to be effective on every attempt to obtain synchronous operation of the motor. The timing cycle can be adjusted, however.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What assurance is there that the rotor will lock into step at the synchronous speed with the use of a timing relay?
2. If the motor fails to achieve synchronous operation, what action is necessary?

UNIT 40 Synchronous Automatic Motor Starter

Objectives After studying this unit, the student will be able to:

- Describe how an out-of-step relay protects the starting winding of a synchronous motor
- Describe the action of a polarized field frequency relay in applying and removing dc field excitation on a synchronous motor
- Connect synchronous motors and controllers which use out-of-step relays and polarized field frequency relays to achieve automatic motor synchronization
- Recommend troubleshooting solutions for problems

An automatic synchronous motor starter can be used with a synchronous motor to provide automatic control of the startup sequence. That is, the controller automatically sequences the operation of the motor so that the rotor field is synchronized with the revolving magnetic field of the stator.

There are two basic methods of starting synchronous motors automatically. In the first method, full voltage is applied to the stator winding. In the second method, the starting voltage is reduced. A commonly used method of starting synchronous motors is the across-the-line connection. In this method, the stator of the synchronous motor is connected directly to the plant distribution system at full voltage. A magnetic starter is used in this method of starting.

A polarized field frequency relay can be used for the automatic application of field excitation to a synchronous motor.

ROTOR CONTROL EQUIPMENT

Field Contactor

The field contactor opens both lines to the source of excitation, figure 40-1. During starting, the contactor also provides a closed field circuit through a discharge resistor. A solenoid-operated field contactor is similar in appearance to the standard dc contactor. However, for this dc operated contactor, the center pole is normally closed. It is designed to provide a positive overlap between the normally closed contact and the two normally open contacts. This overlap is an important feature because it means that the field winding is never open. The field winding of the motor must always be short-circuited through a discharge resistor or connected to the dc line. The coil of the field contactor is operated from the same direct-current source that provides excitation for the synchronous motor field.

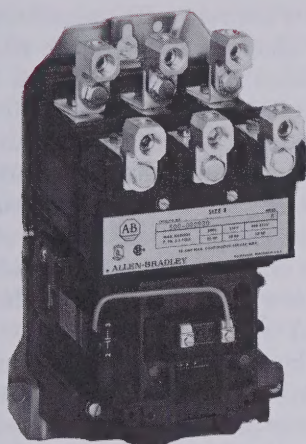


FIG. 40-1 Magnetic contactor used on synchronous starter for field control (Courtesy Allen-Bradley Company)

Out-of-Step Relay

The squirrel cage winding, or starting (amortisseur) winding will not overheat if a synchronous motor starts, accelerates, and reaches synchronous speed within a time interval determined to be normal for the motor. In addition, the motor must continue to operate at synchronous speed. Under these conditions, adequate protection for the entire motor is provided by three overload relays in the stator winding. The squirrel cage winding, however, is designed for starting only. If the motor operates at subsynchronous speed, the squirrel cage winding may overheat and be damaged. It is not unusual for some synchronous motors to withstand a maximum locked rotor interval of only five to seven seconds.

An out-of-step relay (OSR), figure 40-2, is provided on automatic synchronous starters to protect the starting winding. The normally closed contacts of the relay will open to deenergize the line contactor under the following conditions:

1. the motor does not accelerate and reach the synchronizing point after a preset time delay.

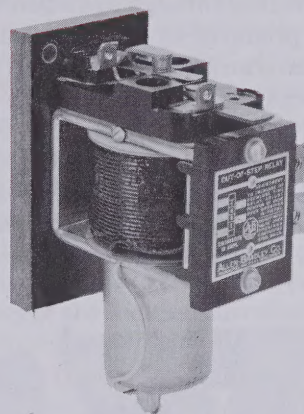


FIG. 40-2 Out-of-step relay used on synchronous starters (Courtesy Allen-Bradley Company)

2. the motor does not return to a synchronized state after leaving it.
3. the amount of current induced in the field winding exceeds a value determined by the core setting of the out-of-step relay.

As a result, power is removed from the stator circuit before the motor overheats.

Polarized Field Frequency Relay

A synchronous motor is started by accelerating the motor to as high a speed as possible from the squirrel cage winding and then applying the dc field excitation. The components responsible for correctly and dependably applying and removing the field excitation are a *polarized field frequency relay* (PFR) and a reactor, figure 40-3.

The operation of the frequency relay is shown in figure 40-4. The magnetic core of the relay has a direct-current coil (C), an induced field-current coil (B), and a pivoted armature (A) to which contact (S) is attached. Coil C is connected to the source of dc excitation. This coil establishes a constant magnetic flux in the relay core. This flux causes the relay to be polarized. Superimposed on this magnetic flux in the relay core is the alternating magnetic flux produced by the alternating induced rotor field current flowing

in coil B. The flux through armature A depends on the flux produced by ac coil B and dc coil C. Coil B produces an alternating flux of equal positive and negative magnitude each half-cycle. Thus, the combined flux flowing through armature (A) is much larger when the flux from coil B opposes that from coil C. In figure 40-4(A), the flux from coil B opposes the flux from dc coil C, resulting in a strong flux being forced through

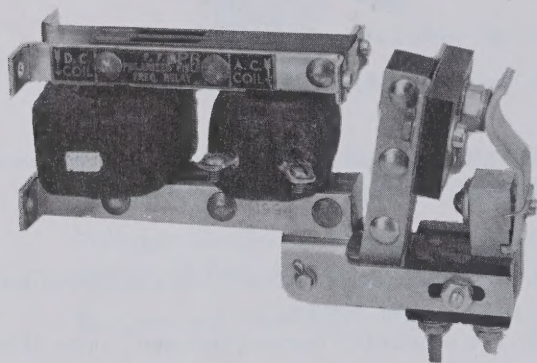


FIG. 40-3 Polarized field frequency relay with contacts in normally closed position (Courtesy Allen-Bradley)

armature A of the relay. This condition is shown by the lower shaded loops of figure 40-4(C). One-half cycle later, the flux produced by coil B reverses and less flux flows through armature A. This is due to the fact that the flux from coil B no longer forces as much flux from coil C to take the longer path through armature A. The resultant flux is weak and is illustrated by the small, upper shaded loops of figure 40-4(C). The relay armature opens only during the period of the induced field current wave, which is represented by the small, upper loops of the relay armature flux.

As the motor reaches synchronous speed, the induced rotor field current in relay coil B decreases in amplitude. A value of relay armature flux (upper shaded loop) is reached at which the relay armature A no longer stays closed. The relay then opens to establish contact S. Dc excitation is then applied at the point indicated on the induced field current wave.

Excitation is applied in the direction shown by the arrow. The excitation is opposite in polarity to that of the induced field current at the point of application. This requirement is necessary to

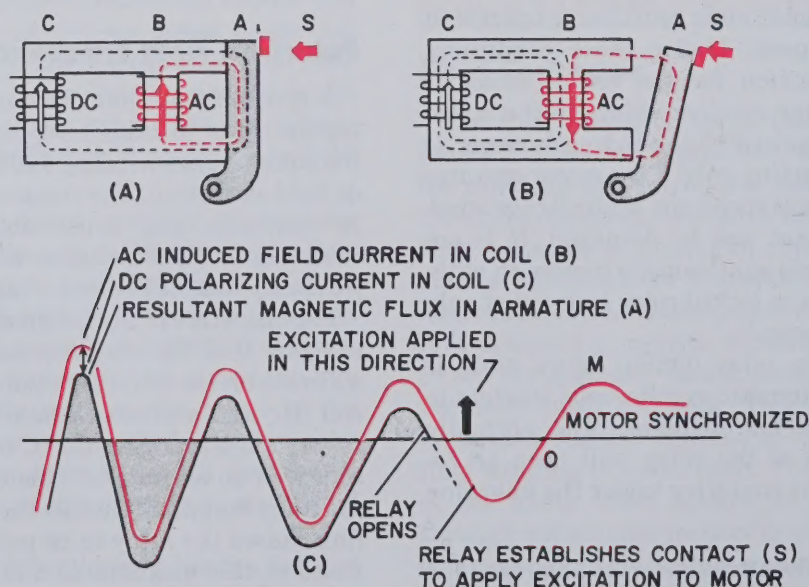


FIG. 40-4 Polarized field frequency relay operation (Courtesy Electric Machinery Mfg. Co.)

compensate for the time needed to build up excitation. The time interval results from the magnetic inertia of the motor field winding. Because of the inertia, the dc excitation does not become effective until the induced current reverses (point O on the wave) to the same polarity as the direct current. The excitation continues to build up until the motor is synchronized as shown by point M on the curve.

Figure 40-5 indicates the normal operation of the frequency relay. Dc excitation is applied to the coil of the relay at the instant the synchronous motor is started. When the stator winding is energized, using either full voltage or reduced voltage methods, line current is allowed to flow through the three overload relays and the stator winding. Line frequency currents are induced in the two electrically independent circuits of the rotor: (1) the squirrel cage or starting windings and (2) the field windings. The

current induced in the field windings flows through the reactor. This device shunts part of the current through the ac coil of the frequency relay, the coil of the out-of-step relay, the field discharge resistor, and finally to the normally closed contact of the field contactor. The flux established in the frequency relay core pulls the armature against the spacer and opens the normally closed relay contacts, figure 40-5. As the motor accelerates to the synchronous speed, the frequency of the induced currents in the field windings diminishes. There is, however, sufficient magnetic flux in the relay core to hold the armature against the core. This flux is due to a considerable amount of induced current forced through the ac coil of the frequency relay by the impedance of the reactor at high slip frequency.

At the point where the motor reaches its synchronizing speed (usually 92 to 97 percent of the synchronous speed) the frequency of the

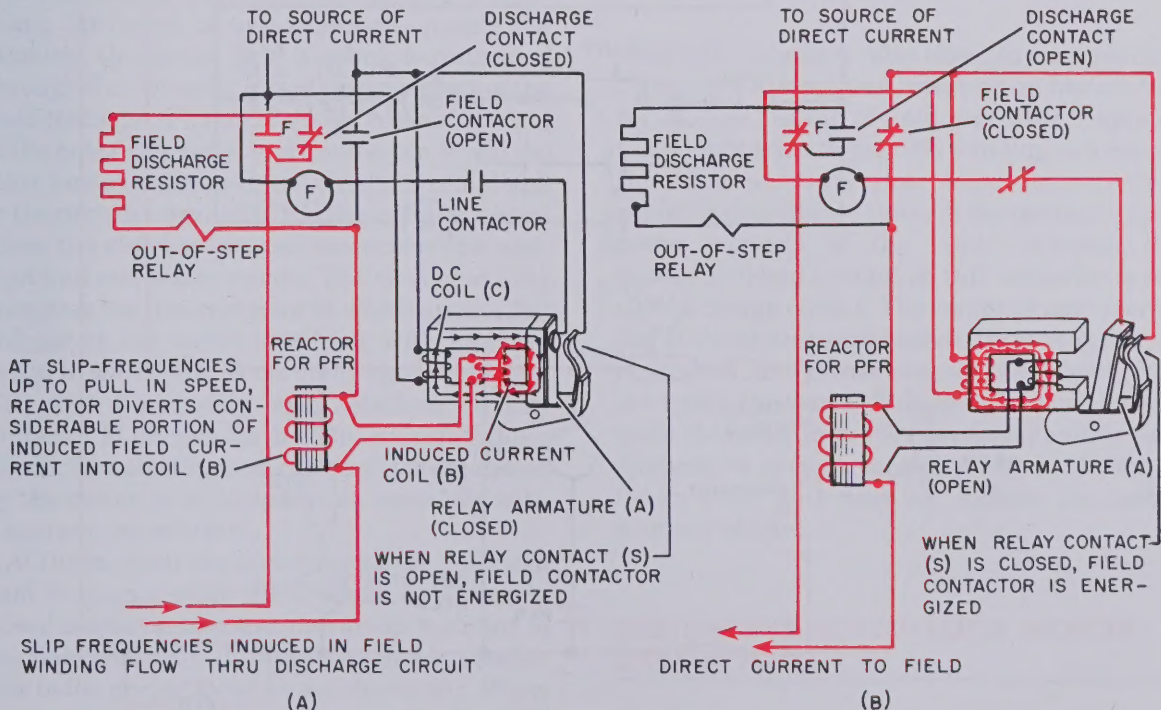


FIG. 40-5 Wiring connections and operation of a polarized field frequency relay (Courtesy Electric Machinery Mfg. Co.)

induced field current is at a very low value. The reactor impedance also is greatly reduced at this low frequency. Thus, the amount of current shunted to the ac coil is reduced to the point where the resultant core flux is no longer strong enough to hold the armature against the spacer. At the moment that the rotor speed and the frequency and polarity of the induced currents

are most favorable for synchronization, the armature is released, the relay contacts close, and the control circuit is completed to the operating coil of the field contactor. Dc excitation is applied to the motor field winding, figure 40-5 (B). At the same time, the out-of-step relay and discharge resistor are de-energized by the normally closed contacts of the field contactor.

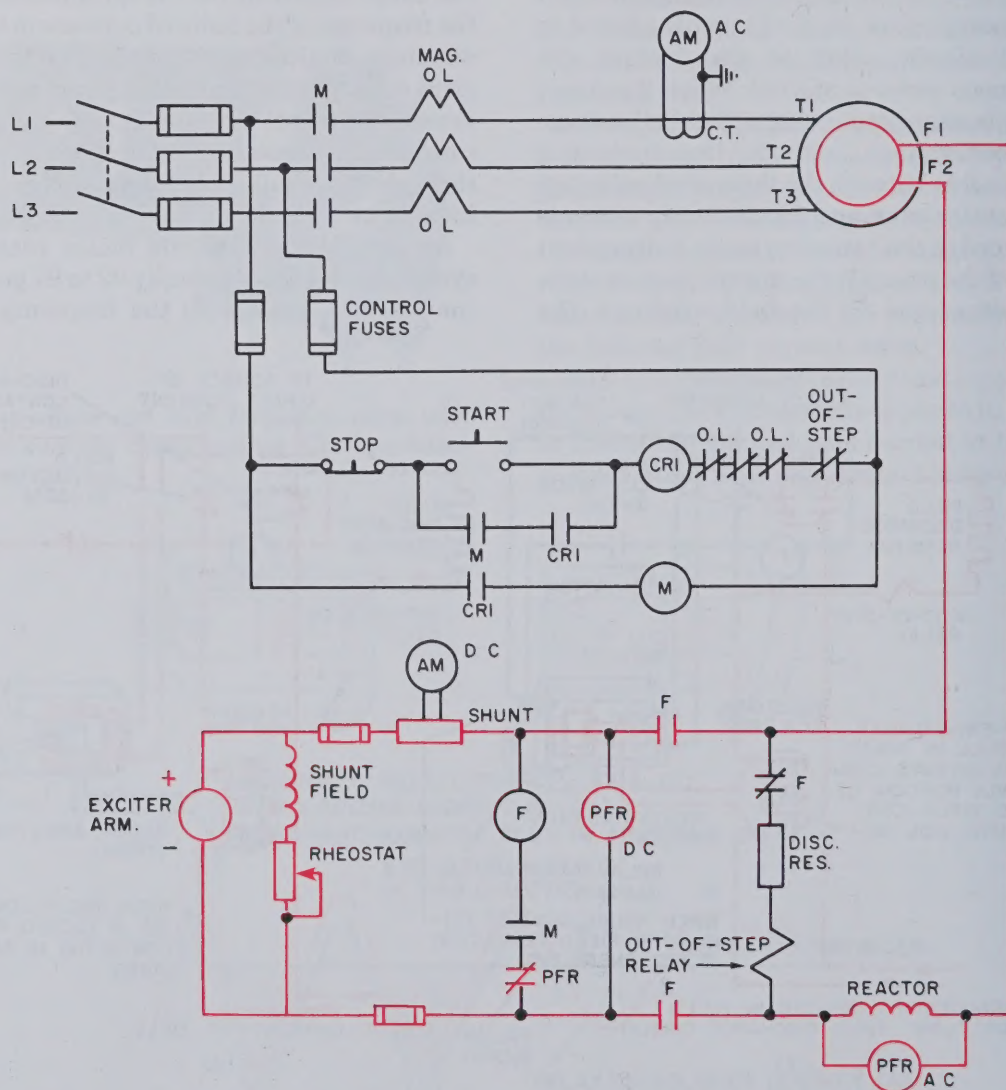


FIG. 40-6 Line diagram for automatic operation of synchronous motor using polarized field frequency relay

An overload or voltage fluctuation may cause the motor to pull out of synchronism. In this case, a current at the slip frequency is induced in the field windings. Part of this current flows through the ac coil of the polarized field frequency relay, opens the relay contact, and removes the dc field excitation. The motor automatically resynchronizes if the line voltage and load conditions return to normal within a preset time interval, and the motor has enough pull-in torque. However, if the overload and low-voltage conditions continue so that the motor can not resynchronize, then either the out-of-step relay or the overload relays activate to protect the motor from overheating.

SUMMARY OF AUTOMATIC STARTER OPERATION

The line diagram in figure 40-6 shows the automatic operation of a synchronous motor. For starting, the motor field winding is connected through the normally closed power contact of the field contactor (F), the discharge resistor, the coil of the out-of-step relay, and the reactor. When the start button is pressed, the circuit is completed to the control relay coil (CR1) through the control fuses, the stop button, and contacts of the overload and out-of-step relays. The closing of CR1 energizes the line contactor M which applies full voltage at the motor terminals with overload relays in the circuit. A normally open contact on CR1 and a normally open interlock on line contactor M provide the hold-in, or maintaining circuit. The starting and running current drawn by the motor is indicated by an ammeter with a current transformer.

At the moment the motor starts, the polarized field frequency relay (PFR) opens its normally closed contact and maintains an open circuit to the field contactor (F) until the motor accelerates to the proper speed for synchronizing. When the motor reaches a speed equal to 92 to 97 percent of its synchronous speed, and the rotor is in the correct position, the contact of the pola-

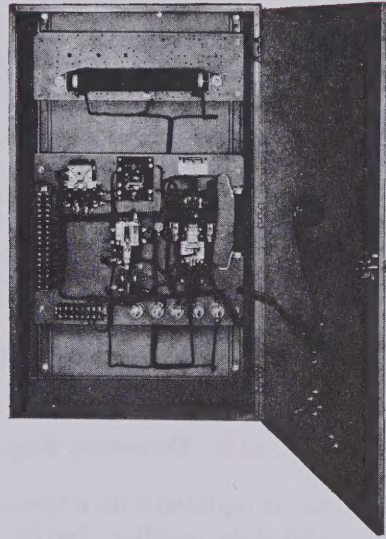


FIG. 40-7 Automatic field application system control panel

rized field frequency relay closes to energize field contactor F through an interlock on line contactor M. The closing of field contactor F applies the dc excitation to the field winding and causes the motor to synchronize. After the rotor field circuit is established through the normally open power contacts of the field contactor, the normally closed contact on this contactor opens the discharge circuit. The motor is now operating at the synchronous speed. If the stop button is pressed, or if either magnetic overload relay is tripped, the starter is de-energized and disconnects the motor from the line. An automatic field application system control panel is shown in figure 40-7. This does not include the motor primary starter.

BRUSHLESS SOLID-STATE MOTOR EXCITATION

An improvement in synchronous motor excitation is the development of the brushless dc exciter. The commutator of a conventional direct-

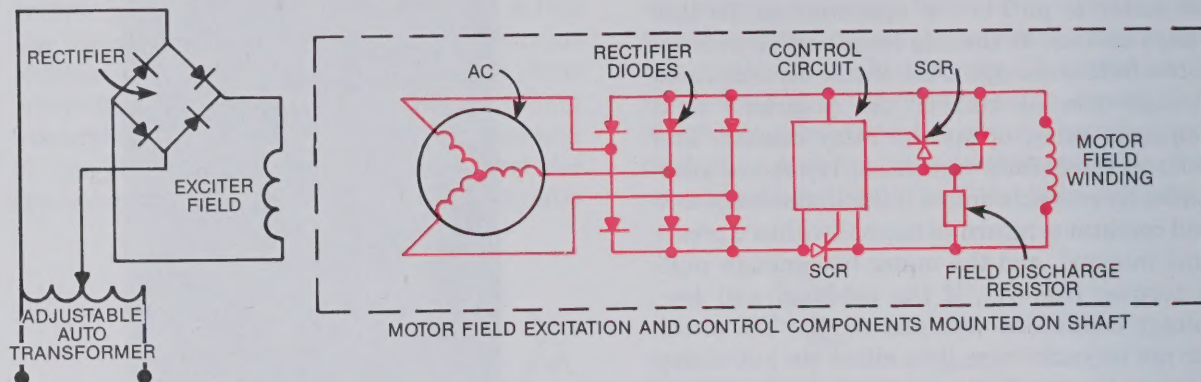


FIG. 40-8 Elementary diagram of a brushless solid-state motor field excitation

connected exciter is replaced with a three-phase, bridge-type, solid-state rectifier. The dc output is then fed directly to the field winding. A simplified circuit is shown in figure 40-8. This scheme is similar to that of a brushless generator. The motor mounted exciter receives its excitation and control (normally supplied with the line control unit) from a small rectifier and adjustable autotransformer supplied from the ac power source. Alternating current from the exciter is fed to a rectifier diode assembly. The dc output of the rectifier is controlled by the static field application system. A rotor-mounted, field-discharge resistor provides a discharge path for

the motor induced field current during starting. The frequency-sensitive static field application system replaces the polarized field frequency relay, the reactor, and the field contactor of conventional brush-type motors. It applies field excitation in such a way that maximum pull-in torque is obtained when the motor reaches a synchronizing speed. Field excitation is automatically removed if the motor is out-of-step. A field monitoring relay (normally supplied with a line control unit) provides instantaneous shut down or unloading on pull-out and provides out-of-step protection for the squirrel cage winding of the motor.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What are the two basic methods of automatically starting a synchronous motor?
2. What is an out-of-step relay?
3. Why is an out-of-step relay used on automatic synchronous starters?
4. Under what conditions will the out-of-step relay trip out the control circuit?
5. What is the last control contact which closes on a starting and synchronizing operation?
6. What influence do both of the polarized field frequency relay (PFR) coils exert on the normally closed contact?

7. Why is the PFR polarized with a dc coil?
8. Approximately how much time (in terms of electrical cycles) elapses from the moment the PFR opens to the moment the motor actually synchronizes?
9. How does the ac coil of the PFR receive the induced field current without receiving the full field current strength?
10. Why is a control relay (CR1) used in figure 40-6?
11. On a brushless rotor, how is dc obtained?

SECTION NINE

A series of approximately 10 thin, parallel horizontal white lines spanning the width of the page, located below the 'SECTION NINE' header.

DIRECT-CURRENT CONTROLLERS

- UNIT 41** About DC Motors
- UNIT 42** Across-the-line Starting
- UNIT 43** Use of Series Starting Resistance
- UNIT 44** Manual Faceplate Starters
- UNIT 45** Compensating and Definite Time Control Starting
- UNIT 46** Solid-State Adjustable Speed Control

UNIT 41 About DC Motors

Objectives After studying this unit, the student will be able to:

- Cite applications of dc motors
- Describe the construction and electrical features of dc motors
- Draw diagrams of dc motor types
- Reverse the direction of rotation of dc motors
- Describe base speed, above and below speeds
- Describe motor connection precautions
- Identify dc motor terminal connections

APPLICATION

The generation of electrical energy and its conversion to mechanical energy is the basis of our industrial structure. It is a fact that direct-current motors are used primarily for industrial purposes. By controlling the voltages supplied to the motor windings, a wide range of motor speeds can be obtained. The ability to control the speed of dc motors makes them valuable for factory hoists and cranes, where heavy loads must be started slowly and then accelerated quickly.

Dc motors are also used in such precision applications as printing presses and steel mill production operations.

MOTOR CONSTRUCTION

The essential features and parts of dc motors and generators are the same. The dc motor has field

coils, armature coils and a commutator with brushes, see figure 41-1.

The Field

A strong magnetic field is provided by the field windings of the individual field poles. The magnetic polarity of the field pole system is arranged so that the polarity of any one magnetic field pole is opposite to that of the poles adjacent to it such as north and south. The field structure of a motor has at least two pairs of field poles. However, motors with four or more pairs of field poles are also used.

The Armature

The armature or rotating member of a dc motor is a cylindrical iron assembly mounted directly on the motor shaft, figure 41-1. Windings are embedded in slots in the surface of the armature. These windings connect to segments

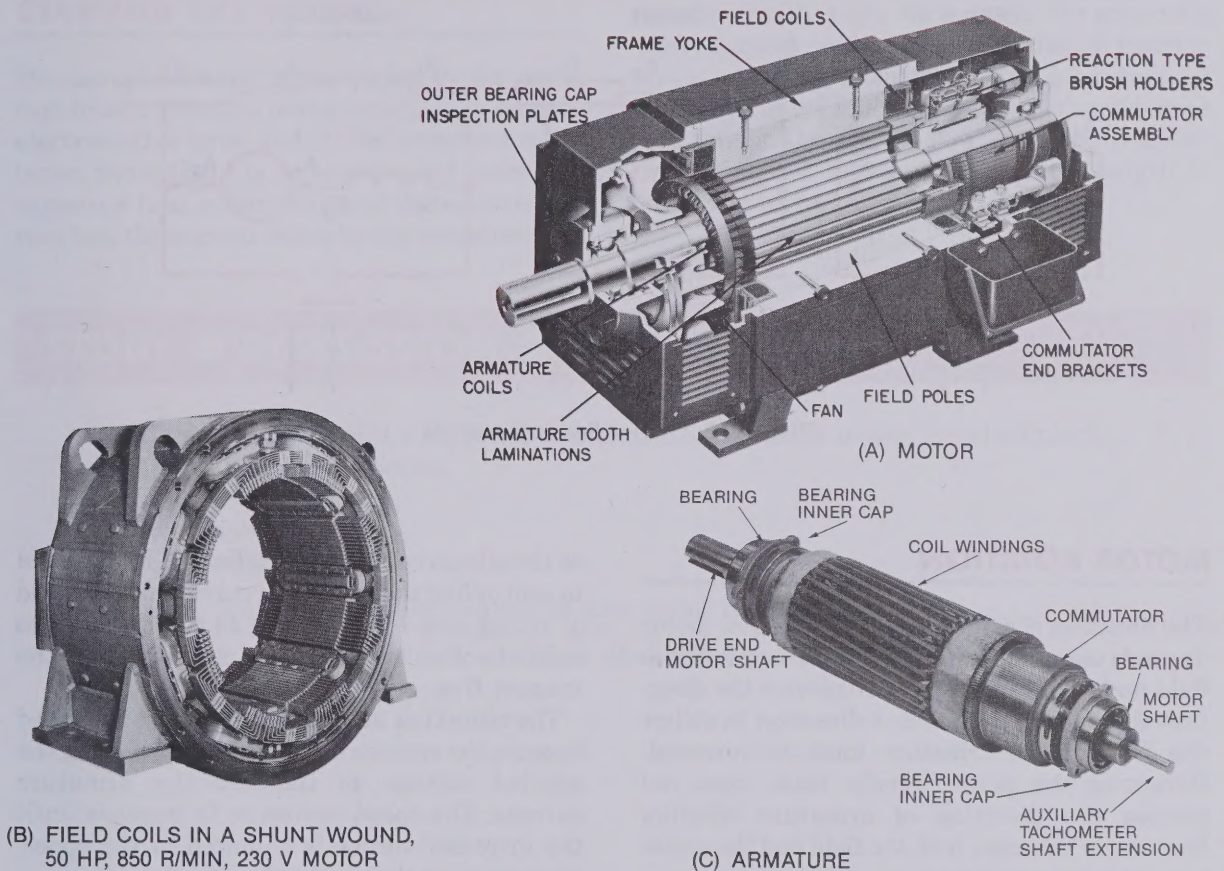


FIG. 41-1 Dc motor, field structure, and armature assembly (Courtesy Reliance Electric Co.)

of the commutator. Direct current is fed to the armature windings by carbon brushes which press against the commutator segments. The commutator changes the direction of the current in the armature conductors as they pass across field poles of opposite magnetic polarity. Continuous rotation in one direction results from these reversals in the armature current.

TYPES OF DC MOTORS

Three types of dc industrial motors are widely used: series, shunt and compound. The type of motor used is based upon the mechanical requirements of the applied load.

As shown in figure 41-2, the *series* motor field is connected in series with the armature. The wire used for the windings must be large enough to pass armature current. The field is labeled S1 and S2.

The field circuit of the *shunt* motor is connected in shunt (parallel) with the armature. Rheostat R is connected in the shunt field circuit (F1, F2). The rheostat is used to increase or decrease resistance in the field circuit; this, in turn, varies the magnetic field flux to control the motor speed. The rheostat is external to the motor.

The *compound* motor has both a shunt and a series field winding.

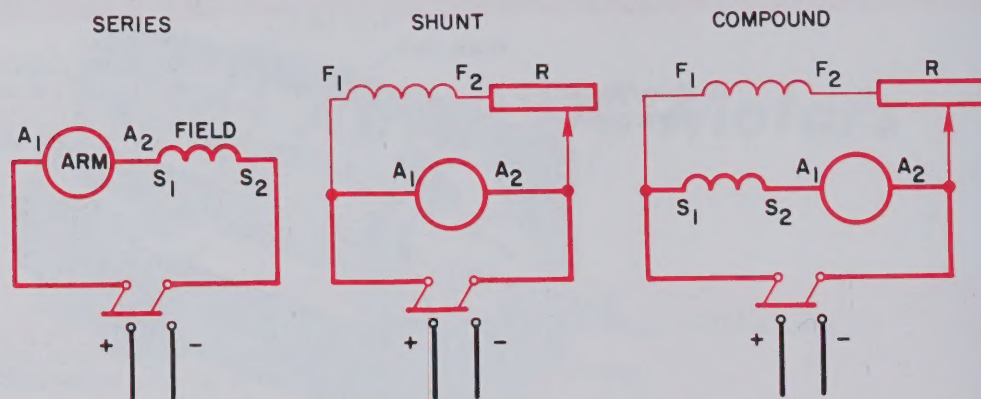


FIG. 41-2 Motor field connections

MOTOR ROTATION

The direction of armature rotation of a dc motor depends upon the direction of the current in the field and armature circuits. To reverse the direction of rotation, the current direction in either the field or the armature must be reversed. Reversing the power supply leads does *not* reverse the direction of armature rotation because, in this case, both the field and the armature currents are reversed.

SPEED CONTROL

Dc motors are operated below normal speed by reducing the voltage applied to the armature circuit. Resistors connected in series with the armature may be used to reduce the voltage. As a result, the motor speed is reduced below the base speed.

A dc motor may be operated above its rated speed (base speed) by reducing the strength of the field magnetic flux, see figure 41-2. A rheostat connected in the field circuit varies the field circuit resistance, the field current, and the field flux.

The same results are obtained by using solid-state electronic devices. Solid-state devices, such

as the silicon controlled rectifier (SCR), are used in controlling the amount of current flow instead of acting as a resistor, such as the rheostat, to regulate the current flow and thereby the magnet flux.

The reduction in field flux increases the speed because the counter emf is reduced, allowing the applied voltage to increase the armature current. The speed continues to increase until the increased torque is balanced by the opposing torque of the mechanical load.

CAUTION: Since the motor speed increases with a decrease in field flux, the shunt field circuit of a dc motor should never be opened when the motor is operating. This is particularly true when the motor is running freely without a load. An open field may cause the motor to rotate at speeds that are dangerous to both the machine and the operator. For this reason, some larger motors are protected against excessive speed by a field rheostat having a no-field release feature. This device disconnects the motor from the power source if the field circuit opens.

If a dc motor must be operated above base speed, be sure to check with the motor manufacturer for the safe operating speed. Do not depend on any controller to protect the motor from excessive speeds unless the limit is checked and preset on the controller.

STARTING THE MOTOR

Two factors limit the current taken by the armature from a direct-current source: (1) the counter electromotive force, and (2) the armature resistance. Since there is no counter emf when the armature is at a standstill and its resistance is very low, the current taken by the armature will

be abnormally high. As a result, the armature current must be limited by an external resistor or a starting rheostat. This procedure is described in the following units. With solid-state equipment, the current flow is limited by allowing a gradual increase of current strength to start the motor.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Draw diagrams of the following dc motors, including the proper terminal markings and field rheostats.
 - a. Series
 - b. Shunt
 - c. Compound

2. How is the direction of rotation of a dc motor reversed?

3. Why is the shunt field circuit never allowed to open while operating?

Either field or Armature leads Reversed
Motor will run away

Across-the-line

Objectives

After studying this unit, the student will be able to:

Objectives After studying this unit, the student will be able to:

- Describe across-the-line starting for small dc motors
- State why a current limiting resistor may be used in the starting circuit for a dc motor
- Connect across-the-line starters used with small dc motors
- Recommend troubleshooting solutions for across-the-line starters
- Draw diagrams for three motor starter control circuits

Small dc motors can be connected directly across the line for starting because a small amount of friction and inertia is overcome quickly in gaining full speed and developing a counter emf. Fractional horsepower manual starters (discussed in unit 2) or magnetic contactors and starters (unit 3) are used for across-the-line starting of small dc motors, figure 42-1.

Magnetic across-the-line control of small dc motors is similar to ac control or to two- or three-wire control. Some dc across-the-line starter coils have dual windings because of the added load of multiple break contacts and the fact that the dc circuit lacks the inductive reactance which is present with ac electromagnets. Both windings are used to lift and close the contacts, but only one winding remains in the holding position. The starting (or lifting) winding of the coil is designed for momentary duty only. In figure 42-2, assume that coil M is energized momentarily by the start button. When the starter is closed, it maintains itself through the normally

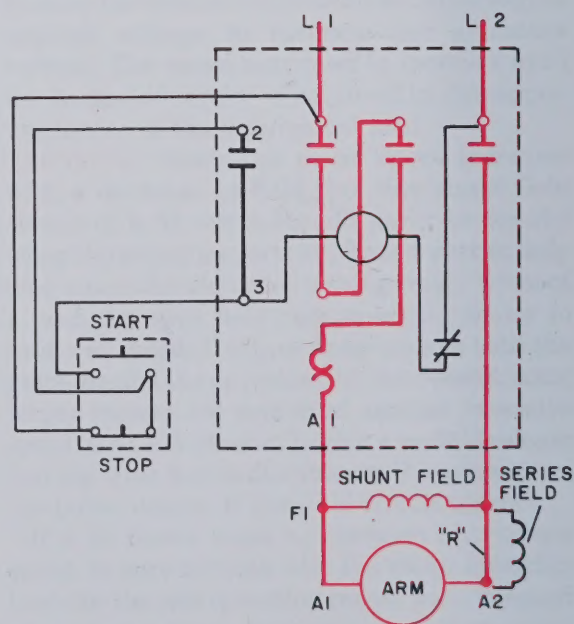


FIG. 42-1 Dc full voltage starter wiring diagram. Connection ("R") is removed with use of series field.

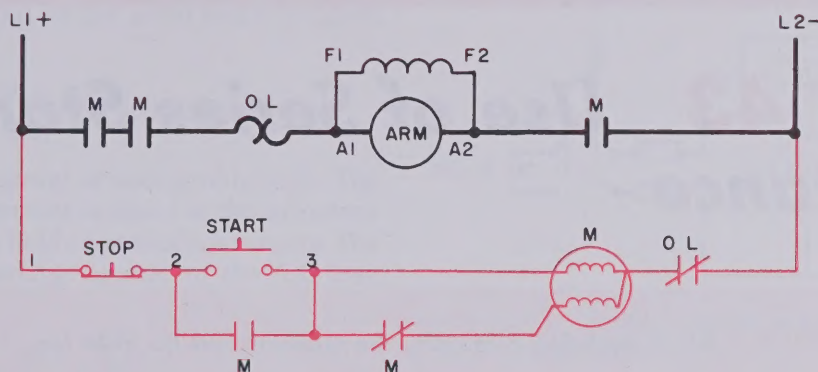


FIG. 42-2 Line diagram of dc motor starter with dual winding coil

open maintaining contact (M) and the upper winding of the coil since the normally closed contact (M) is now open. Power contacts M close, and the motor starts across the full line voltage. The double-break power contacts are designed to minimize the effects of arcing. (Dc arcs are greater than those due to ac.)

Figure 42-3 shows another control method used to start a dc motor. In this method, a current limiting resistor is provided to prevent coil burnout. It is used to limit a continuous duty current flow to some coils or when the coils are overheating.

The coil first receives the maximum current required to close the starter. It then receives the minimum current necessary to hold in the contacts and for continuous duty through the current limiting resistor.

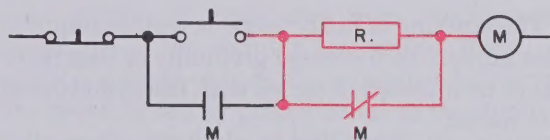


FIG. 42-3 Dc starting circuit using current limiting resistor

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Why may small dc motors be started directly across the line?
Small current flow
2. When using a coil that is not designed for continuous duty, what may happen if a resistor is not added to the circuit?
Counter EMF is small - Lack of inertia
Smoke the Coil
3. What is the purpose of a double-break power contact?
Minimize arcing

UNIT 43 Use of Series Starting Resistance

Objectives After studying this unit, the student will be able to:

- List the two factors which limit the current taken by a motor armature
- Explain why it is necessary to insert resistance in the proper part of a dc motor circuit on starting
- Calculate the amount of series resistance required for a dc motor at different speeds during the starting period

The starting of fairly large dc motors requires that current be increased gradually or that resistance be inserted in series with the armature of the motor.

Two factors which limit the current taken by a motor armature from a given line are the *counter emf* and the *armature resistance*. When the motor is at a standstill, there is no counter emf, nor is there inductive reactance such as in an ac motor. Therefore, the current taken by the armature will be abnormally high unless the dc supply is increased gradually, as with solid-state equipment, or an external current limiting resistor is used.

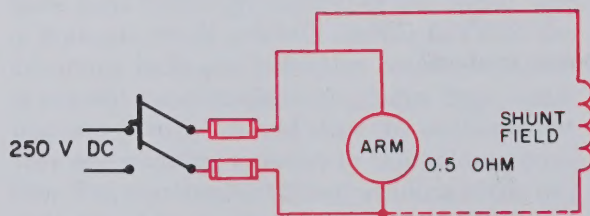


FIG. 43-1 This 25-ampere dc motor will draw 500 amperes from the line on starting without armature resistance

Figure 43-1, illustrates a shunt motor connected directly across a 250-volt line. The resistance of the armature is 0.5 ohm. The full-load current taken by the motor is 25 amperes and the shunt field current is one ampere. The resulting armature current at *full load* is 24 amperes.

It was stated in a previous unit that the *counter emf* developed by a motor is proportional to the speed of the motor if the field is constant. In addition, the counter emf equals the applied voltage minus the armature (IR) drop. The current through the armature can be found using Ohm's law as follows:

$$I = \frac{E - E_c}{R_a}$$

where: I = armature current, amperes
 E = line voltage, volts
 E_c = counter emf, volts
 R_a = armature resistance, ohms

When there is no starting resistance in the circuit, the current through the armature at the

instant of starting, for the shunt motor in figure 41-1 is:

$$I = \frac{250 - 0}{0.5} = 500 \text{ amperes}$$

This starting current is undesirably high. The total starting current is equal to the armature current plus the field current of one ampere. The ratio of the starting current to the full load current is:

$$\frac{501}{25} = 20.04$$

The excessive torque and heat produced by this current may harm the motor and the load attached to it. In addition, it may cause the insulation to overheat on starting and the burning of the armature.

These effects can be eliminated by connecting a resistance in series with the armature, figure 43-2. The resistance reduces the starting armature current to approximately 1.5 times the full-load current value. The resistance is then gradually removed from the circuit.

The value of this series resistance is determined by solving the previous equation for R . Remember that the armature resistance (R_a) must be subtracted:

$$R = \frac{E - E_c}{I} - R_a$$

$$I = 24 \times 1.5 = 36 \text{ A}$$

When the motor is at a standstill, the series resistance is equal to:

$$R = \frac{250 - 0}{36} - 0.5 = 6.44 \text{ ohms}$$

Resistors are also rated in watts. The following formula can be used to find the power requirement of the resistor:

$$I^2 R = P$$

$$36 \times 36 \times 6.44 = 8346 \text{ watts}$$

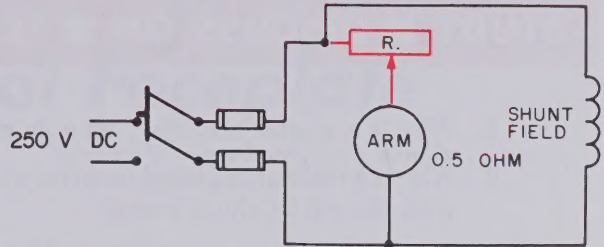


FIG. 43-2 Starting resistors are used to eliminate high starting currents

The proper resistor can be selected by knowing the required resistance and the power value in watts.

The required series resistance can be determined for some intermediate speed in the starting period of the motor. In this case, solve for the counter emf at the speed in question and then obtain the resistance from the formula given. Since the counter emf differs from the applied voltage only by the armature (IR) drop, the speed is nearly proportional to the applied voltage. For example, at half speed, the counter emf is equal to:

$$\frac{50\% \text{ speed}}{100\% \text{ speed}} = \frac{\text{Voltage at Half-speed}}{250}$$

$$\text{Voltage at Half-speed} =$$

$$250 \times \frac{50\%}{100\%} = 250 \times 1/2 = 125 \text{ volts}$$

The resistance required at half speed is equal to:

$$R = \frac{250 - 125}{36} - 0.5 = 2.97 \text{ ohms}$$

The counter emf can be found at the full load:

$$E_c = E - (IR_a)$$

$$E_c = 250 - (24 \times 0.5)$$

$$E_c = 250 - 12$$

$$E_c = 238 \text{ volts}$$

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Why is a starter necessary on a dc motor?
2. Why is a resistance placed in series with the armature only, rather than in series with the entire shunt motor?
3. If an armature has a resistance of 0.5 ohm, what series resistance must be used to limit the current to 30 amperes across a 230-volt circuit at the instant of starting? What is the power rating?
4. What resistance must be used when the motor in question 3 reaches 50% of its rated speed?

$$\frac{\text{Volts } 230}{\text{Amps } 30} = \frac{7.6}{7.1} \sim \text{Resistor}$$

$$P = E \cdot I$$

$$230 \cdot 30 = 6900 \text{ Watts}$$

$$P = I^2 R$$

$$30^2 \cdot 7.1 = 6390 \text{ Watts}$$

UNIT 44 *Manual Faceplate Starters*

Objectives After studying this unit, the student will be able to:

- Identify terminal markings for dc shunt motors and manual faceplate starters
- Describe the operation of a three-terminal dc manual faceplate starter
- Connect direct current motors and manual faceplate controllers
- Recommend solutions for troubleshooting problems with dc motors and manual faceplate controllers
- Describe the difference between a three-terminal and a four-terminal dc manual starter

THREE-TERMINAL DC FACEPLATE STARTER

A three-terminal, dc manual starter is a device that contains the following components: (1) the series resistors required for starting a motor, (2) the contacts and switching arm required to transfer through these resistors, and (3) a device which automatically reinserts this resistance in the circuit in the event of a line voltage failure.

Figure 44-1 is a diagram of a three-terminal starter connected to a shunt motor. The direct-current line is connected to the starter and motor through a switch and suitable fuses. The contact arm has an insulated handle or knob for the operator's use. By moving the contact arm from the off position to the first contact (a) of the starting resistance, the armature is connected across the line. Note that the armature is in series with the total starting resistance. The shunt field, in series with the holding coil, is also connected across the line. In this mode of operation, the initial current inrush to the armature

is limited by the resistance. At the same time, the field current is at the maximum value to provide a good starting torque.

As the contact arm is moved to the right, the starting resistance is reduced and the motor gradually accelerates. When the last contact (b) is reached, the armature is connected directly across the line, thus, the motor is at full speed.

The holding coil is connected in series with the shunt field to provide a "no field release". If the field circuit opens by accident, the motor speed will become excessive if the armature remains connected across the line. To prevent this increase in speed, the holding coil is demagnetized and spring action returns the arm to the off position.

Note that the starting resistance is in series with the field when the arm is in the running position. The effect of this resistance on the speed of the motor is negligible because the starting resistance is only a small percentage of the shunt field resistance. Therefore, the current and voltage drop are small.

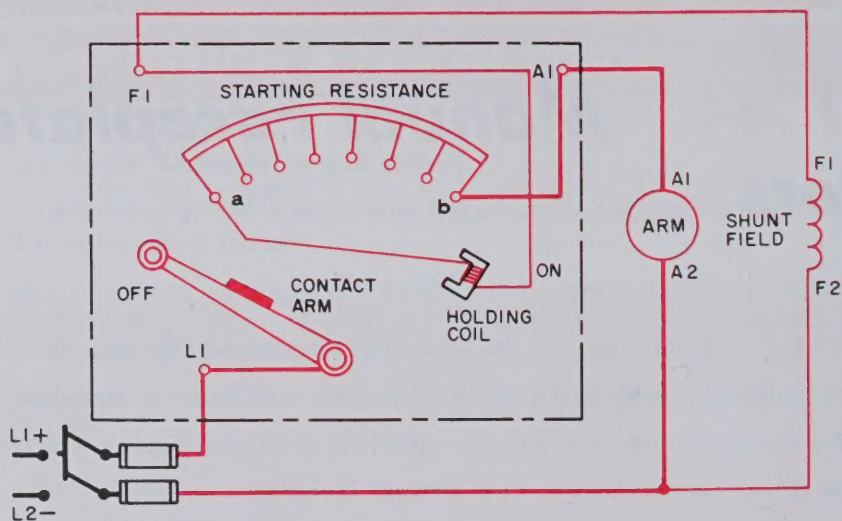


FIG. 44-1 Three-terminal dc manual starter diagram

When this type of starter is operated, the arm must be moved slowly to limit the current inrush to the motor. The arm should not be held too long on any contact between (a) and (b) since the starting resistance is designed to carry the starting current for a short time only.

In other words, the speed of the motor should not be controlled by holding the arm for any length of time on an intermediate position between contacts (a) and (b). This faceplate

starter is designed for motor starting and not for speed regulating.

If a motor has an external resistance in series with the field to provide speed control, then the three-terminal starter is not a suitable choice for operating the motor. The external resistance may reduce the current in the field and holding coil down to a value that is too low to hold the arm against the action of its spring. Therefore, the arm will return to the off position.

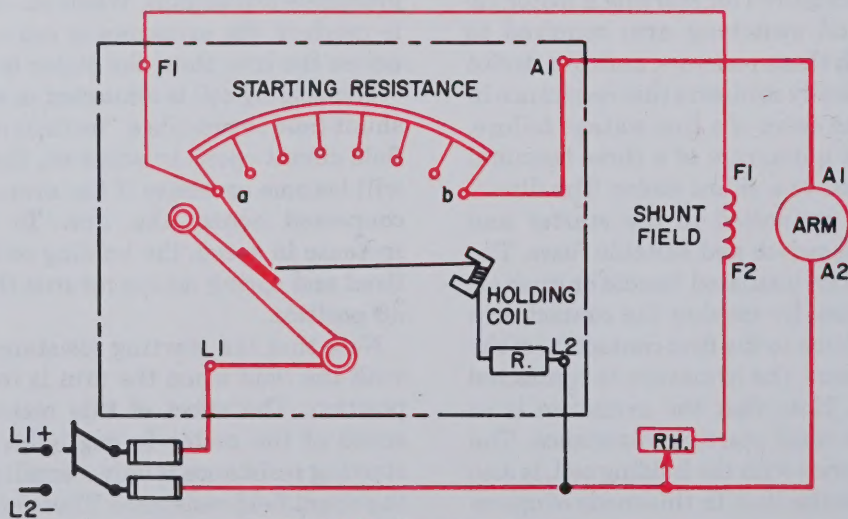


FIG. 44-2 Four-terminal starter

FOUR-TERMINAL DC FACEPLATE STARTERS

In applications where many motor speeds are required, a four-terminal faceplate starter is used with the motor. The four-terminal starter, figure 44-2, differs from the three-terminal starter in that the holding coil is not connected in series with the shunt field. Instead, it is connected across the line in series with a resistor. This resistor limits the current in the holding coil to the desired value. The holding coil serves as a no-voltage release rather than as a no-field release. If the line voltage drops below the desired value, the attraction of the holding coil is decreased. The spring then pulls the contact arm back to the off position.

The four-terminal starter is used when it is desired to increase the speed of the motor by inserting a field rheostat, figure 44-3, to weaken the field current. The motor is started by slowly moving the arm from (a) to (b), where it is held by the holding coil. The speed of the motor is controlled by varying the field rheostat. The speed is at a minimum when the resistance is cut out entirely from the circuit, strengthening

the field. When all of the resistance is included in the circuit, weakening the field, the motor speed is at a maximum value. The armature speeds to gain the required counter emf to limit the armature current.

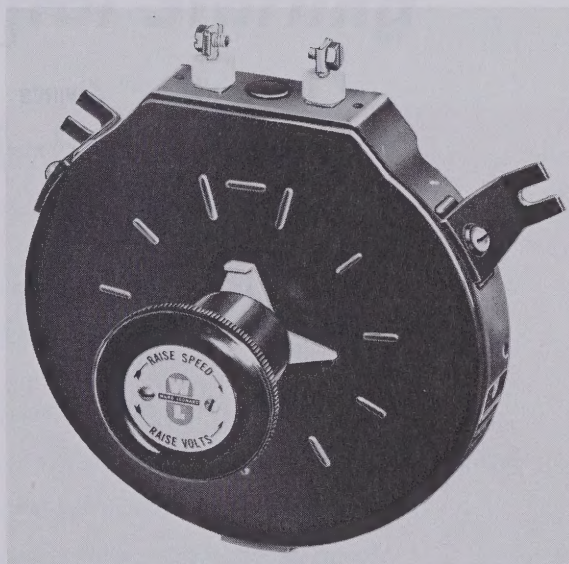


FIG. 44-3 Circular plate rheostat (Courtesy Ward Leonard Electric Co., Inc.)

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Why is the holding coil used?
2. Why is the resistance cut out in steps rather than all at once?
3. With a fully loaded motor, what will happen if the starting arm is held on a contact between (a) and (b) for a long time?
4. What occurs in the three-terminal starter if the field circuit opens?
5. Why is a resistor placed in series with the holding coil?
6. Explain how the rheostat in series with the field controls the speed of the motor.
7. Why is the holding coil not placed in series with the field in the four-terminal starter?
8. What will happen in the four-terminal starter if the voltage fails?

9. How many wires are contained in the conduits running to the starter shown in figure 44-4?

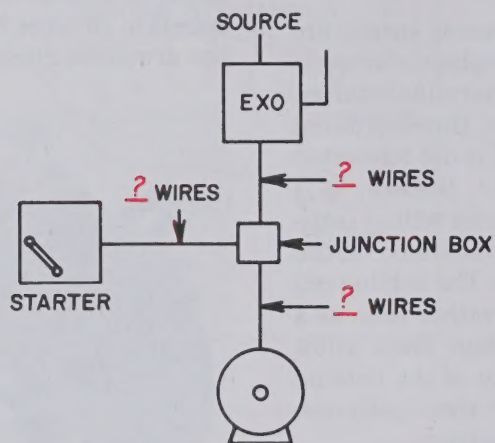


FIG. 44-4

UNIT 45 *Compensating and Definite Time Control Starting*

Objectives After studying this unit, the student will be able to:

- Identify terminal markings for a direct-current compound motor and a counter emf controller
- Describe the operation of a counter emf controller
- State the purpose of a relay connected across the armature of a counter emf controller
- Connect dc motors and counter emf controllers
- Recommend troubleshooting solutions for problems with counter emf controllers
- Describe how a definite timer is used to provide time limit acceleration
- Describe the use and operating sequence of a field accelerating relay
- Describe the use and operating sequence of a field failure relay

COMPENSATING TIME ACCELERATION

This type of controller automatically adjusts the starting time intervals, depending upon the load connected to the motor. For example, since a heavy load has more inertia for the motor to overcome, a longer time is required to build up the counter emf. Thus, a longer starting period is required. The following starter is an example.

COUNTER EMF CONTROLLER

When a dc motor starts, the generated counter emf across the armature is low. As the motor

accelerates, the counter emf increases. When the voltage across the motor armature reaches a certain value, a relay is actuated to reduce the starting resistance at the right time.

Figure 45-1 shows the schematic connection diagram for a dc motor controller, using the principle of counter emf acceleration. When the start button is pressed, contactor M is energized and the main contact (M) is closed. The current path is then complete from L1 through the resistor (R1-R2), the armature (A1-A2), and the series field (S1-S2) to L2.

To prevent the contactor from opening, the maintaining contact (M) is operated from the coil (M). This means that a shunt is placed around the start button. When the start button is

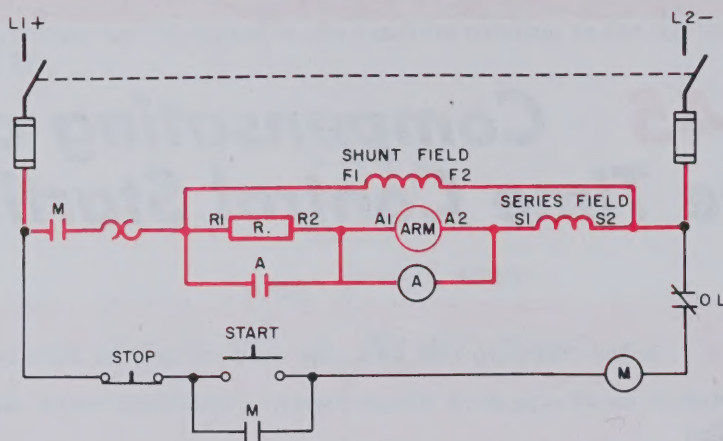


FIG. 45-1 Line diagram of a counter emf controller

released, M remains energized through the maintaining contacts (M) until the stop button is pressed.

There is a high voltage drop across R1-R2, but a counter emf is not present across the armature. As the motor accelerates, the current is reduced. When the counter emf across the armature reaches a value equal to a certain percentage of the full value, relay A (connected across the armature) closes contact (A). Thus, resistor R1-R2 is removed from the circuit and the motor is placed directly on the line.

VOLTAGE-SENSITIVE RELAY

The relay (A) is a voltage-sensitive relay, figure 45-2. It is commonly used to sense the dc motor armature voltage. This voltage is an indication of motor speed. The voltage-sensitive relay is frequently used in the following applications: hoist controllers; reversing-plugging to stop; and applying armature shunt contactors on multistep slowdown and acceleration circuits. Because the relay is adjustable for pick-up and drop-out, one of its many uses is to control multisteps of acceleration as a motor starter. Figure 45-1 shows one relay and one resistor for

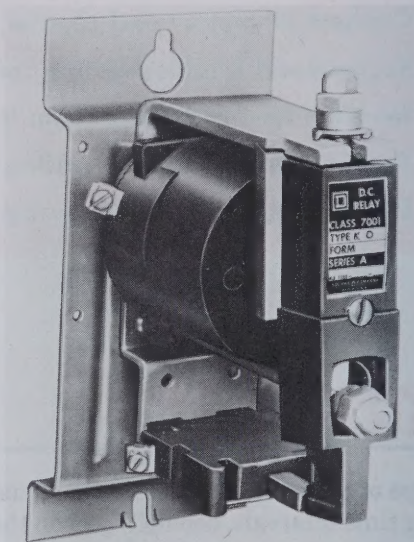


FIG. 45-2 Dc voltage sensitive relay for dc motor armature voltages (Courtesy Square D Co.)

one step of acceleration. For heavier motors and loads, additional relays and resistors can be added to increase the points of acceleration. The additional relays must be adjusted to insure that the resistances will be cut out of the circuit at the proper times as the motor accelerates.

FIELD ACCELERATING RELAY

A *field accelerating* relay, or a full field relay, figure 45-3, is used with starters to control adjustable speed motors. This type of relay provides the full field during the starting period and limits the armature current during sudden speed changes. The coil of the field accelerating relay is connected in series with the motor armature. When there is a current inrush at startup, or when a sudden speed increase causes excessive armature currents, the coil closes the relay contacts. The closed contacts bypass the shunt field rheostat. The full shunt field strength is provided on starting and excessive armature currents are prevented during speed changes.

FIELD FAILURE RELAY

A field failure relay is a single-pole control relay, figure 45-3. The contacts of the relay are connected in the control circuit of the main contactor. The coil is connected in series with the shunt field. If the shunt field fails, the relay coil is de-energized and the relay contact opens the

circuit to the motor starter, disconnecting the motor from the line. The field failure relay is a safety feature that can be added to a starter to prevent the motor from greatly increasing its speed if the field is opened accidentally.

DEFINITE TIME CONTROL STARTING

A timing relay provides a definite timed interval which is used to control acceleration while a motor is being brought up to speed. The acceleration steps are controlled by resistors inserted in the line ahead of the motor. The definite time limit acceleration provided by the timing relays means that the resistors remain in the line for a fixed time period before the motor is connected across the line. A typical dc reduced voltage magnetic starter (less enclosure) using timing relays is shown in figure 45-4A. A schematic for this starter is also shown.

Time limit acceleration is preferred for some applications. Other methods of acceleration (compensating time, counter emf, and current limiting) have the disadvantage that the motor

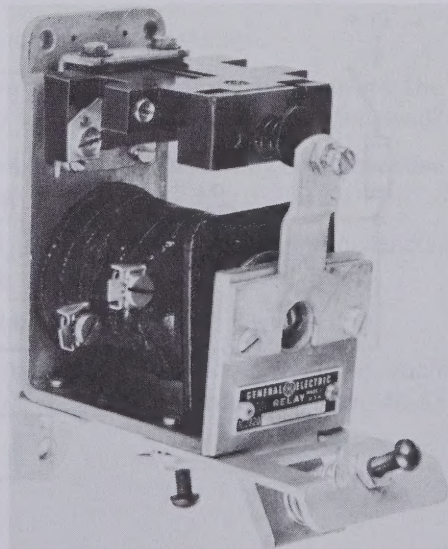
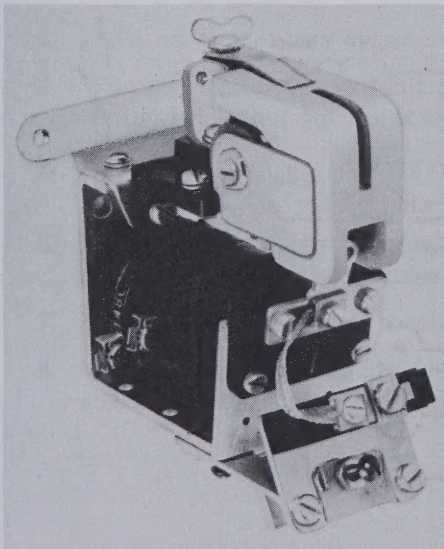


FIG. 45-3 Dc field accelerating relay (left) and dc field failure relay (Courtesy General Electric Co.)

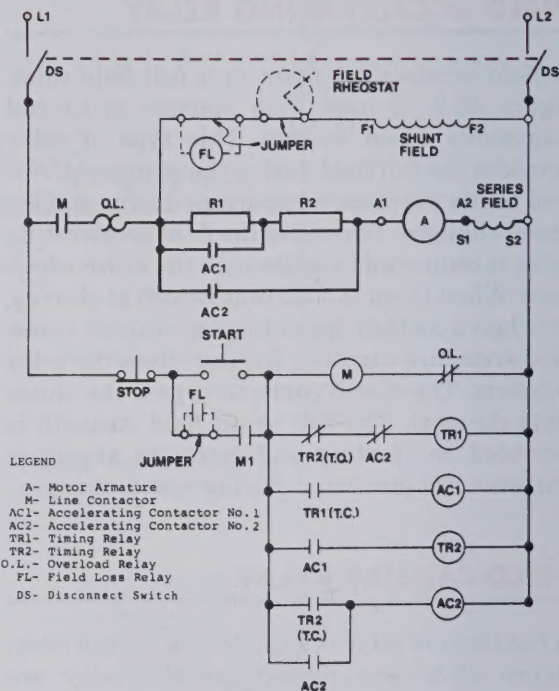
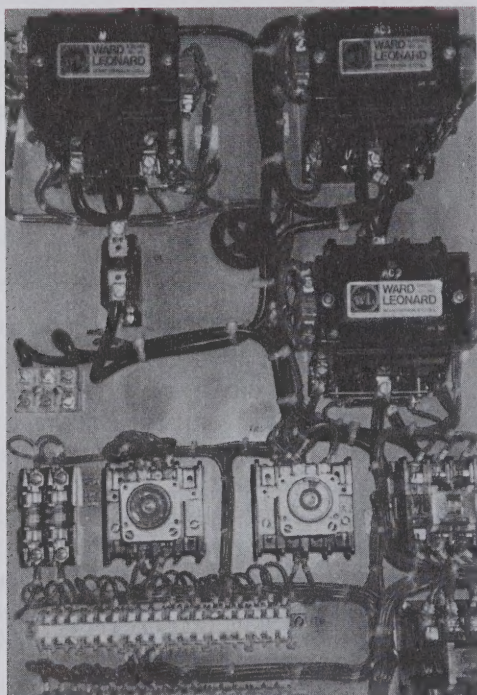


FIG. 45-4(A) Dc reduced voltage magnetic starter and schematic diagram (Courtesy of Ward Leonard Electric Co., Inc.)

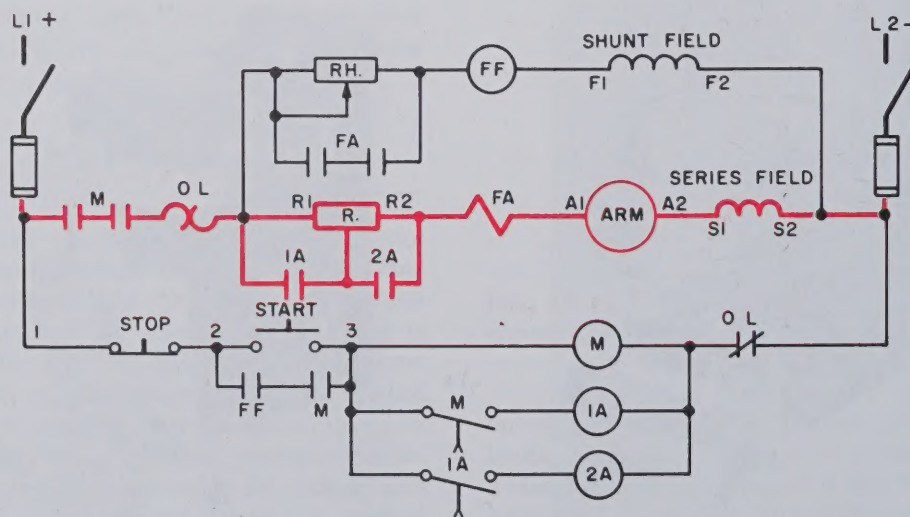


FIG. 45-4(B) Schematic diagram for definite time limit starting, using timing relays, field accelerating relays, and field failure relays

might not accelerate enough to close the running contactor that bypasses the resistors. In other words, the resistors might remain in the circuit and could burn out. This hazard is eliminated by the use of time limit acceleration, because the running contactor is closed automatically after a definite time interval.

As shown in the typical schematic in figure 45-4B, the closing of the start button energizes coil M. This coil, in turn, instantaneously closes the heavy power contacts (M). The motor is then started through the starting resistor. The double-break contacts (M) are used to minimize the dc arc. The shunt field and field failure relay (FF) are energized at this same moment. The control contacts (FF and M) close and maintain the circuit across the start button. The series coil of the field accelerating relay (FA) receives the maximum current flow and closes contacts FA

to shunt the circuit across the shunt field rheostat. Since the maximum field strength is present, there is more counter emf and excessive armature currents are prevented.

Main contactor M also activates a normally open, delay-in-closing contact (M). At the end of the time delay of the timing cycle, it energizes the first accelerating relay (1A). Power contact 1A cuts out one step of resistance and also activates the preset timing cycle (1A). The normally open, delay-in-closing contact (1A) energizes the second accelerating relay (2A). This action places the armature across the line. Time limit controllers can be used with series, shunt, or compound wound dc motors. These controllers can drive pumps, fans, compressors, and other classes of machinery when the load varies over a wide range and when automatic or remote control is desired.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Why is this type of controller called a counter emf controller?
2. What physical characteristic distinguishes between a *main contactor* and a *relay*?
3. Draw an elementary diagram with three points of acceleration.
4. What protection is available from excessive starting currents in the event the timing relays cut out the starting resistors too rapidly for the connected load?
5. How does a field accelerating relay prevent current excess that may occur because of adjusting the rheostat to change speeds?
6. How do individual timers, which have only light, single-pole control contacts, control the acceleration steps of a large dc motor?
7. How may more steps of acceleration be added to a starter?
8. Why is use made of double-break contacts or contacts connected in series, such as contacts FA across the rheostat and M in the armature circuit in figure 45-4?

UNIT 46 *Solid-State Adjustable Speed Control*

Objectives After studying this unit, the student will be able to:

- Describe power conversion
- Tell how solid-state control limits current flow on starting
- Describe methods of feedback for constant speed control
- Discuss armature and field current sensing techniques
- Describe methods of communicating with controllers
- Perform maintenance on solid-state dc adjustable speed control

POWER CONVERSION AND CONTROL

Dc motors are widely used in industry because of their great versatility. They can be operated at a slow speed with a high torque. They can be run constantly at nameplate speed (base speed) or even above base speed (within safe limits), as shown in figure 46-1. It is not necessary to have a dc power plant and distribution system due to the wide use of solid-state rectifiers. Dc is converted at the motor control site from the ac distribution system.

STARTING THE MOTOR

The following factors limit the current flow taken by the armature from the power source:

- (1) the counter electromotive force (emf), and
- (2) the armature resistance.

Since there is no counter emf when the armature is at a standstill, and its resistance is very low, the current taken by the armature on start-up will be abnormally high. As a result, the motor armature is gradually fed an increasing amount of voltage, from zero voltage for start, to full voltage for run. A fully energized field is maintained to generate the counter emf required on run to limit the armature current. Counter emf is gradually built up from start, with an increase in armature speed, to maximum on run.

Motor Speed Control

Motor speed control basics still apply. With full field and armature voltage, the value of revolutions per minute of the motor is the nameplate, or base, speed. When operating the motor below base speed, which is very common, the armature voltage is reduced accordingly. Full field is maintained.

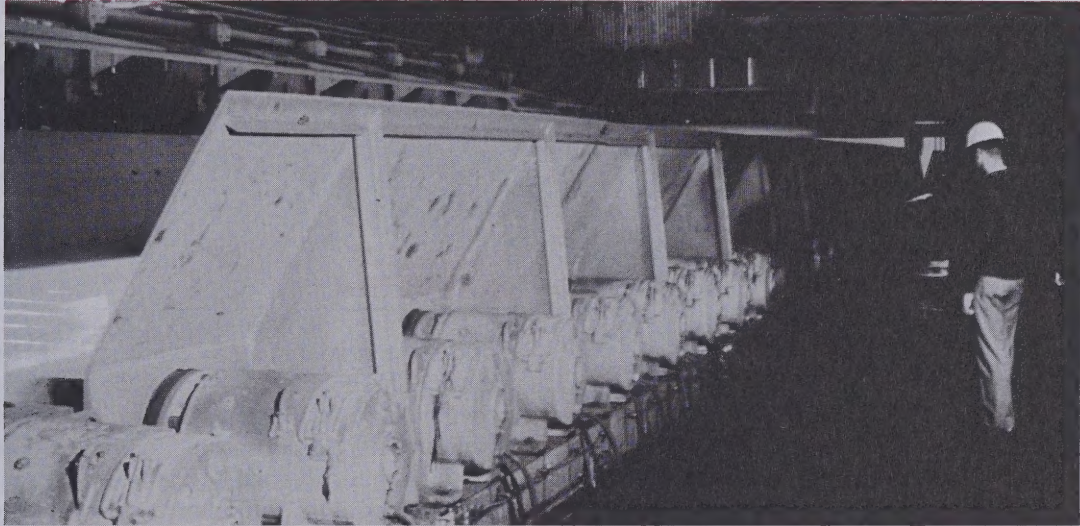
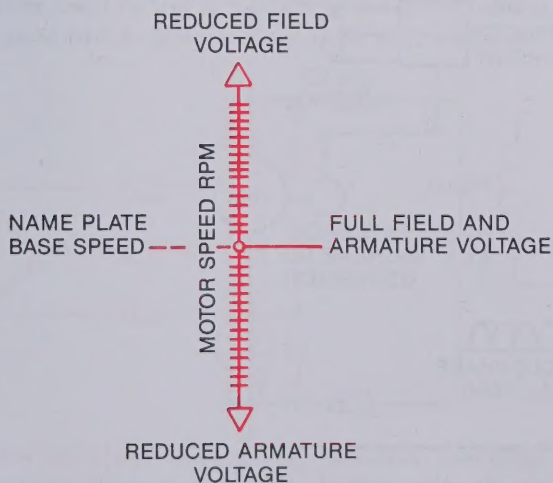


FIG. 46-1 Steel ingot being moved by dc compound-wound motors (Courtesy of General Electric, DC Motor and Generator Department)

If it is necessary to operate the motor above base speed, the field voltage is reduced and armature voltage is fully applied. Refer to Table 46-1. The motor nameplate does not give maximum speed limitations. For a safe operating condition, check with the motor manufacturer for the safe maximum speed limit.

TABLE 46-1 DC Drive Speed Control



DC ADJUSTABLE SPEED CONTROL FROM SINGLE-PHASE AC

A basic dc drive consists of an operators control station that determines when the drive starts and stops. The speed control potentiometer gives a reference signal to the drive controller, as shown in figure 46-2.

Smaller size dc motors often operate from a single-phase ac source. Rectified and controlled dc is fed to the armature of the motor by silicon controlled rectifiers, or thyristors. This method is similar to the solid-state ac reduced voltage starters shown previously. In this case, however, the SCRs are connected to produce controlled dc from the ac line. Figure 46-3 shows a simplified single-phase ac circuit rectified to dc supplying a dc motor. The field circuit is a full-wave dc supply (shown graphically) for a greater field strength when required. Motor speed is preset by the operator control. This electronically adjusts for the proper field and armature current strength for the desired speed. The feedback tachometer generator helps to regulate the amount of dc flowing to the armature for high torque, slower-than-base speeds. The tachometer

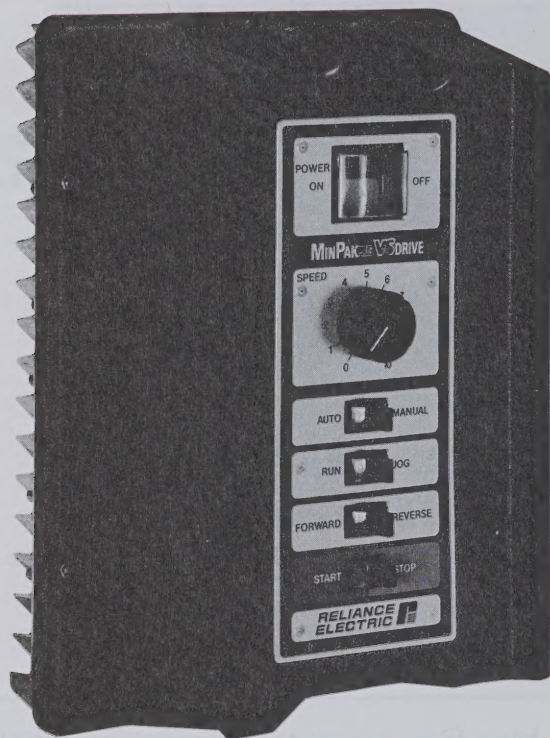


FIG. 46-2 Operator control panel for a dc variable speed control (Courtesy of Reliance Electric Company)

generator output voltage is proportional to its speed. The output voltage is connected to the SCR gate control circuit. A change in speed is detected and immediately corrected to maintain a preset constant speed. Generally, dc motors are run at base speed or below.

INSTALLATION AND MAINTENANCE

Solid-state drives are designed for easy installation. Threaded hub-like power entries are provided for top and bottom conduit entry. Enclosure knockouts are also available and wire entry is made directly to incoming marked power terminals. Sufficient space is allowed around power terminals to assure working room and easy installation of plug-in kits. Refer to figure 46-4. Keeping these drives operating reliably should not be too difficult. Modular construction makes troubleshooting easier. Components can be removed for repair or replacement. Leads disconnect simply by means of plug connectors. Replacement components are accessible. The visual control panel tells where the problems are.

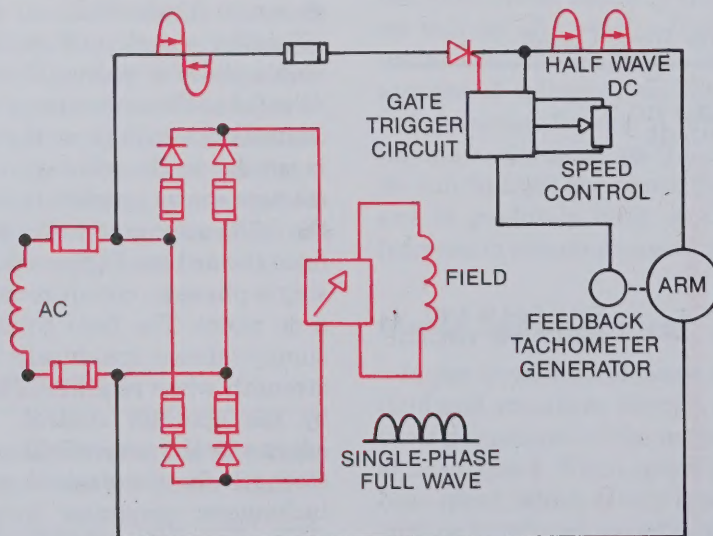


FIG. 46-3 Single-phase ac to dc motor control

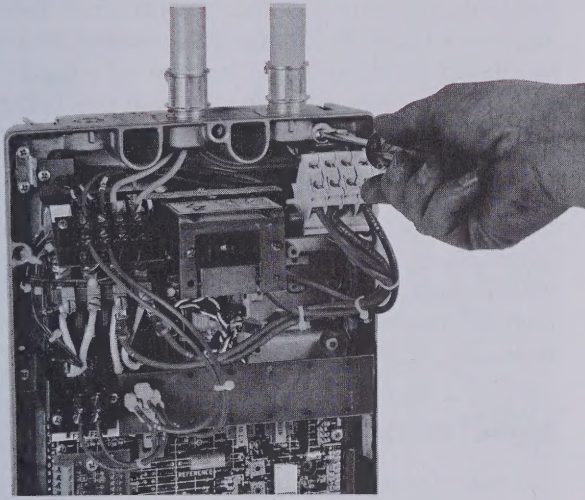


FIG. 46-4(A) Power leads fall straight to incoming termination with ample room for wiring. Note the threaded conduit power entries at the top which permit quick installation (Courtesy of Reliance Electric Company)

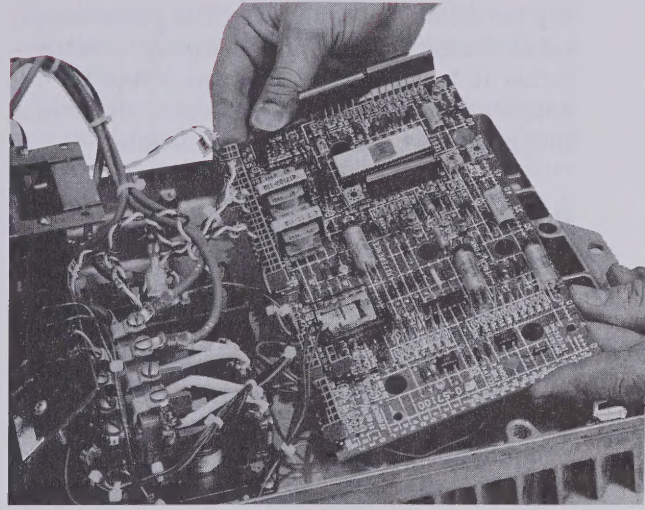


FIG. 46-4(B) Modular design allows for easy troubleshooting (Courtesy of Reliance Electric Company)

DC ADJUSTABLE SPEED CONTROL, THREE-PHASE

Power Supply

Power conversion cells convert incoming three-phase ac power to the highly controllable dc power used in the armature of the drive motor. Figure 46-5A shows a diagram of a three-phase,

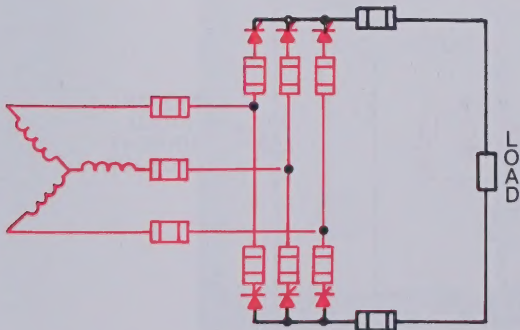


FIG. 46-5(A) Three-phase, full-wave controlled rectifier with connected load

full-wave controlled rectifier connected to a load. The controlled rectifier uses SCRs — not uncontrolled diodes as shown in single-phase rectifiers. Note that some single-phase units use SCRs also. Three-phase rectifiers provide smooth dc compared with half-wave single-phase. This can be seen in figure 46-5B, looking at the top of the dc ripple (A, B, C). This ripple is further refined by filtering it through electronic circuits contain-

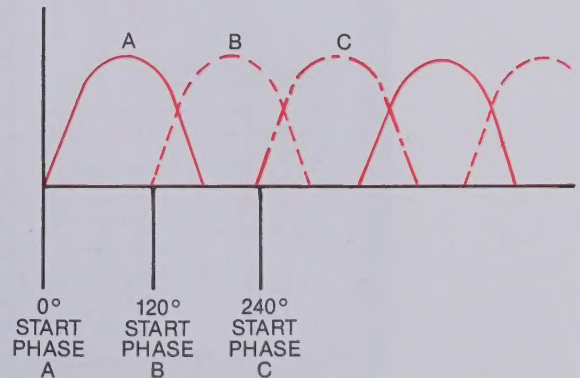


FIG. 46-5(B) Rectified three-phase power

ing inductors and capacitors. The power supply takes the incoming three-phase power and transforms it to the proper voltage levels for the support circuitry, to power the signal electronics, firing circuits, and excitation modules.

Power Control

Figure 46-6 shows a three-phase power circuit for an adjustable speed drive system. These systems are available in sizes ranging from about five to twenty-five hundred horsepower. The circuit diagram shows the circuit configuration of the power conversion system and the motor field excitation module. Three-phase power is routed through the fuse-protected legs of this converter and is delivered to the armature. Fuses on each leg provide better protection than line fuses against “shoot-throughs” and reversing inversion faults. SCRs are mounted with proper heat sinks (heat dissipators). Some of this may be seen in figure 46-7. A main dc contactor isolates the armature when stopped. The motor field may remain energized. If so, its

heat helps prevent harmful moisture from forming in the motor due to condensation in a humid or damp environment. Instead of using a tachometer generator feedback for constant speed control, armature and field current feedback is obtained from shunts, more often used in connecting dc ammeters. These shunts are similar to a resistor. A millivolt drop is read across them, and this information is fed into the speed control circuit. The SCRs then act to control the motor at a constant speed under changing load conditions.

Signal Electronics

A signal electronics module provides the overall drive control. It contains a microprocessor and supporting control electronics mounted on printed wiring boards, figure 46-8. The same signal electronics module usually can be used regardless of the size of the power electronics (with equipment from the same manufacturer). In this way, the cost of the replacement modules inventory is reduced. It is also convenient for the

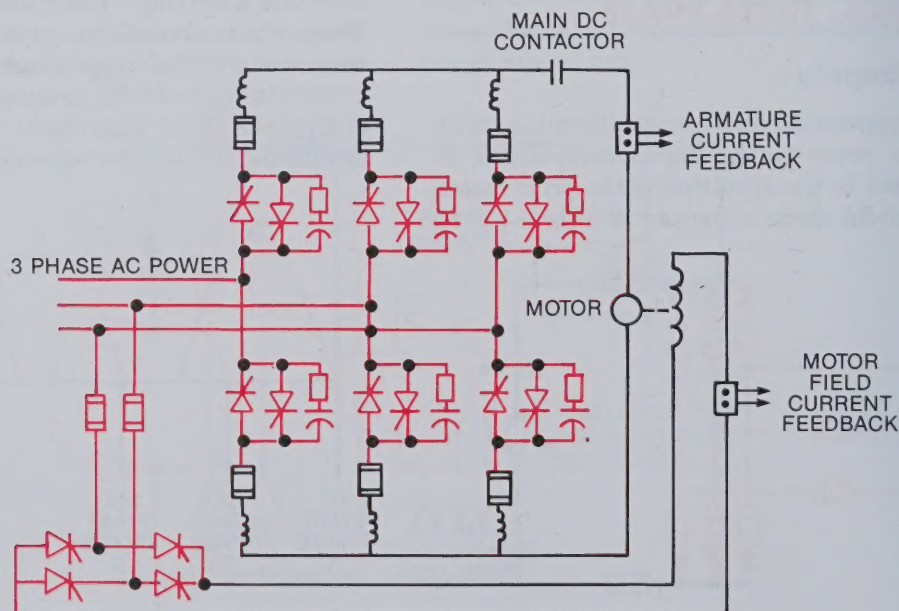


FIG. 46-6 Three-phase ac feeding a dc adjustable speed drive power circuit

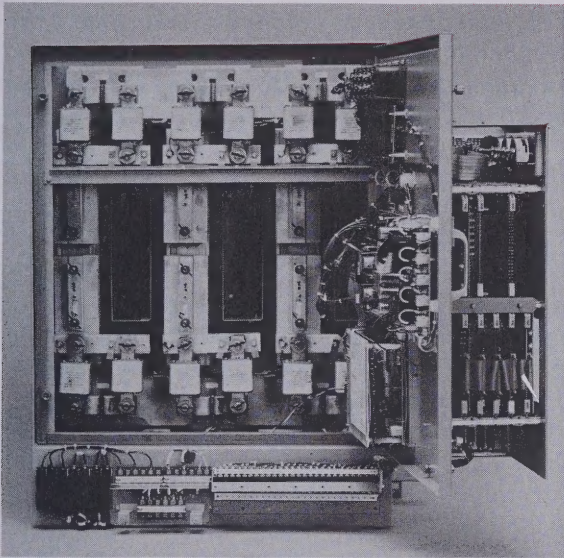


FIG. 46-7 SCRs are mounted with proper heat sinks (Courtesy of General Electric Company, Drive Systems Operation)

maintenance personnel, because modules can be switched or interchanged when diagnosing a problem.

The microprocessor is the center of the control system. In addition to providing the SCR firing circuit, control, regulating functions, and drive sequencing, it can communicate with people. It also responds to feedbacks and reference commands, then adjusts both motor field and armature power accordingly. The microprocessor also provides diagnostic information. To communicate this information, a number of techniques are available. For example, a light-emitting diode display panel provides indication of motor faults, converter faults, alarms, drive status, and drive configuration. If more than one fault occurs, each of the faults will activate a light and the first fault will flash. An amber colored LED is energized on all key circuit boards after the microprocessor control checks each critical circuit. The amber, or white, LED light remains

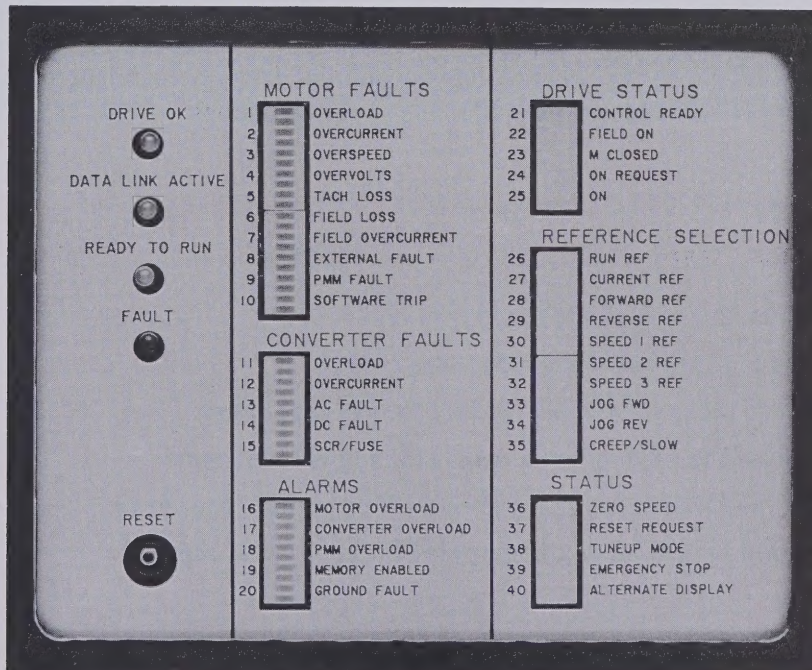


FIG. 46-8 Signal module contains a microprocessor and control electronics mounted on printed wiring boards (Courtesy of General Electric Company, Drive Systems Operations)

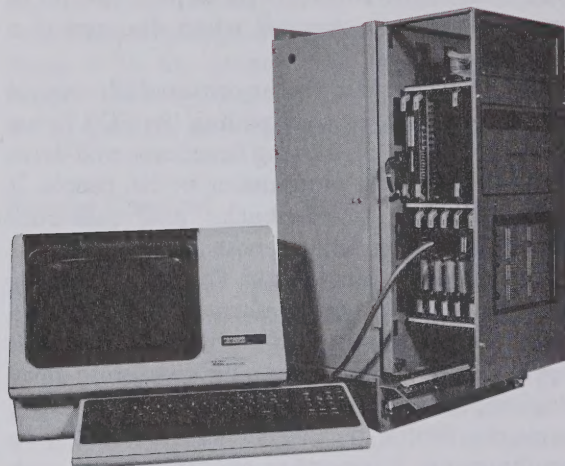


FIG. 46-9 Keyboard and video monitor (Courtesy of General Electric Company, Drive Systems Operations)

energized as long as the circuit is functional. Thyristor cell status lights are energized each time the indicated SCR is fired, thus indicating the operation of the SCR. If a printer is connected, English language and engineering term messages are received from the processor.

This information can be used to interrogate the drive unit. However, a keyboard and video monitor are required to do this. These are seen in figure 46-9.

SELF-TEST DIAGNOSTICS

When power is applied to the drive or when it is requested by an interactive command, each of the circuit boards is sequentially checked by the microprocessor. As each passes the self-test routine, the light for that board is energized and the system progresses to the next board. After the signal electronics have been verified, the microprocessor fires each of the armature circuit SCRs one at a time. An SCR cell voltage sensor is used to indicate if the gating, fuse, and SCR are operational. If both the signal (control) and the power electronics pass the test, the control is released for drive operation. If the test discovers a problem (failed board, SCR cells, fuses, open wire, and so on), the specific fault is displayed on the lighted panel or is printed out, and the drive is not released for starting until the problem is corrected.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Where does the dc motor get its dc power?
2. How does a solid-state device start the motor?
3. Describe methods of feedback control for constant speed.
4. What method is used to sense armature and field current?
5. Describe methods of communication with a machine controller.
6. What might be a first step in troubleshooting a drive control?

SECTION TEN

A series of ten thin, horizontal white lines stacked vertically, serving as a decorative separator between the section title and the main title.

METHODS OF DECELERATION

- UNIT 47** Jogging (inching) Control Circuits
- UNIT 48** Plugging
- UNIT 49** Electric Brakes
- UNIT 50** Dynamic and Regenerative Braking
- UNIT 51** Electric and Electronic Braking

UNIT 47 Jogging (Inching) Control Circuits

Objectives After studying this unit, the student will be able to:

- Define the process of jogging control
- State the purpose of jogging controllers
- Describe the operation of a jogging control circuit using a control relay
- Describe the operation of a jogging control using a control relay on a reversing starter
- Describe the operation of a jogging control using a selector switch
- Connect jogging controllers and circuits
- Recommend solutions for troubleshooting jogging controllers

Jogging, or *inching*, is defined by the National Electrical Manufacturers' Association (NEMA) as "the quickly repeated closure of a circuit to start a motor from rest for the purpose of accomplishing small movements of the driven machine." The term *jogging* is often used when referring to across-the-line starters; the term *inching* can be used to refer to reduced voltage starters. Generally, the terms are used interchangeably because they both prevent a holding circuit.

JOGGING CONTROL CIRCUITS

The control circuits covered in this unit are representative of the various methods that are used to obtain jogging.

Figure 47-1 is a line diagram of a very simple jogging control circuit. The stop button is held

open mechanically, figure 47-2. With the stop button held open, maintaining contact M can not hold the coil energized after the start button is closed. The disadvantage of a circuit connected in this manner is the loss of the lock-stop safety feature. This circuit can be mistaken for a conventional three-wire control circuit, locked off for safety reasons, such as to keep a circuit or machine from being energized. A padlock should be installed for safety purpose.

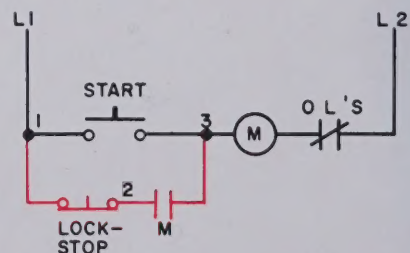


FIG. 47-1 Lock-stop push button in jogging circuit

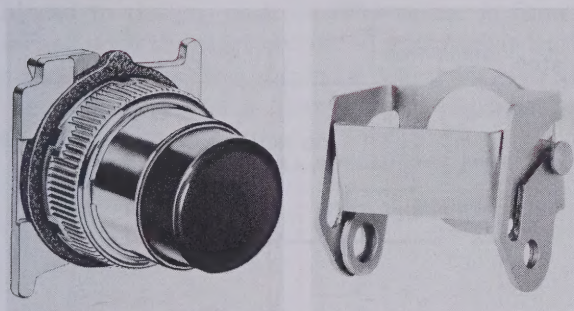


FIG. 47-2 Oiltight push-button operator with extra long button to accept padlock attachment (on right) to provide lockout on stop feature (Courtesy EATON Corp., Cutler-Hammer Products)

If the lock-stop push button is used for jogging, it should be clearly marked for this purpose.

Figure 47-3 illustrates other simple schemes for jogging circuits. The normally closed push button contacts on the jog button in figure 47-3(B) are connected in series with the holding circuit contact on the magnetic starter. When the jog button is pressed, the normally open contacts energize the starter magnet. At the same time, the normally closed contacts disconnect the holding circuit. When the button is released, therefore, the starter immediately opens to disconnect the motor from the line. The action is similar in figure 47-3(A). A *jogging attachment* can be used to prevent the reclosing of the normally closed contacts of the jog button. This device assures that the starter holding circuit is not re-established if the jog button is released too rapidly. Jogging can be repeated by reclosing the jog button; it can be continued until the jogging attachment is removed.

CAUTION: If the circuits shown in figure 47-3 are used without the jogging attachment mentioned, they are hazardous. A control station using such a circuit, less a jogging attachment, can maintain the circuit when the operator's finger is quickly removed from the button. This could injure production workers, equipment, and machinery. This circuit should not be used by responsible people committed to safety in the electrical industry.

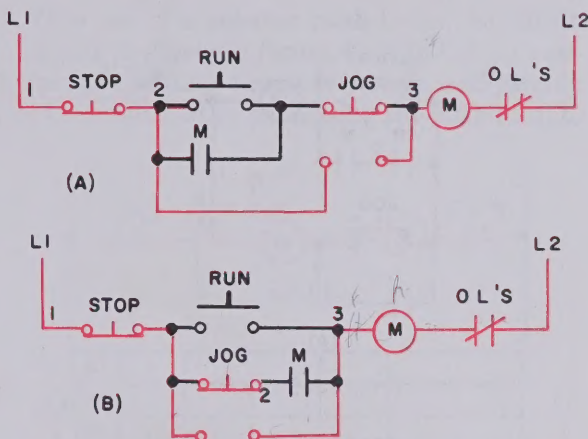


FIG. 47-3 Line diagrams of simple jogging control circuits

JOGGING USING A CONTROL RELAY

When a jogging circuit is used, the starter can be energized only as long as the jog button is depressed. This means the machine operator has instantaneous control of the motor drive.

The addition of a control relay to a jogging circuit provides even greater control of the motor drive. A control relay jogging circuit is shown in figure 47-4. When the start button is pressed, the control relay is energized and a holding circuit is formed for the control relay and the starter magnet. The motor will now run. The jog button is connected to form a circuit to the starter magnet. This circuit is independent of the

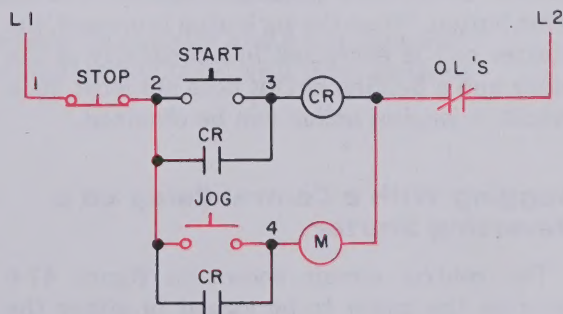
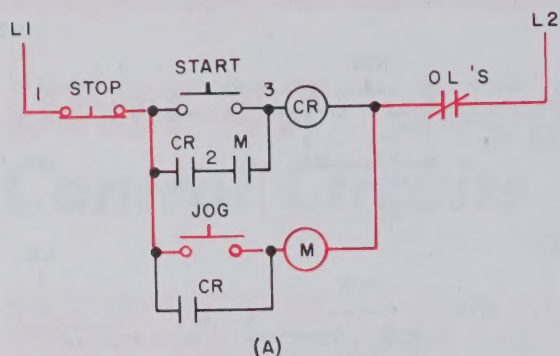
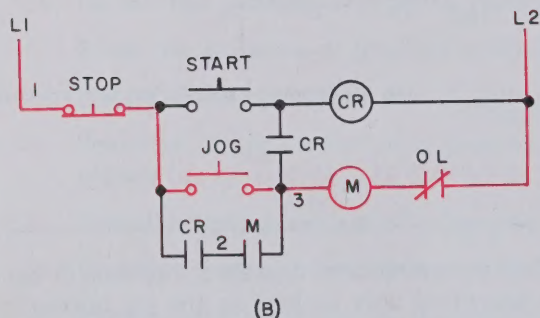


FIG. 47-4 Jogging is achieved with added use of control relay



(A)



(B)

FIG. 47-5 Line diagrams using control relays in typical installations

control relay. As a result, the jog button can be pressed to obtain the jogging or inching action.

Other typical jogging circuits using control relays are shown in figure 47-5. In figure 47-5(A), pressing the start button energizes the control relay. In turn, the relay energizes the starter coil. The normally open starter interlock and relay contact then form a holding circuit around the start button. When the jog button is pressed, the starter coil is energized independently of the relay and a holding circuit does not form. As a result, a jogging action can be obtained.

Jogging With a Control Relay on a Reversing Starter

The control circuit shown in figure 47-6 permits the motor to be jogged in either the forward or the reverse direction while the motor is at standstill or is rotating in either direction.

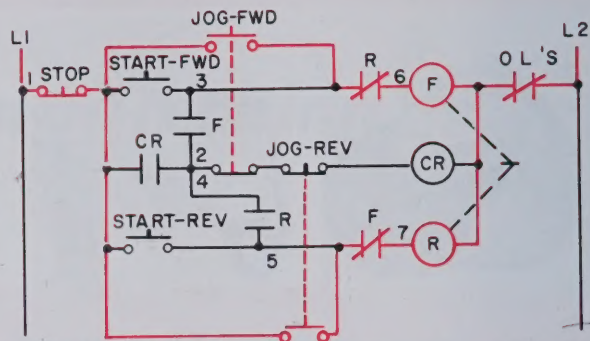


FIG. 47-6 Jogging using control relay on a reversing starter

Pressing either the start-forward button or the start-reverse button causes the corresponding starter coil to be energized. The coil then closes the circuit to the control relay which picks up and completes the holding circuit around the start button. While the relay is energized, either the forward or the reverse starter will also remain energized. If either jog button is pressed, the relay is de-energized and the closed starter is released. Continued pressing of either jog button results in a jogging action in the desired direction.

Jogging With a Selector Switch

The use of a selector switch in the control circuit to obtain jogging requires a three-element control station with start and stop controls and a selector switch. A standard duty, two-position selector switch is shown connected in the circuit in figure 47-7. The starter maintaining circuit is disconnected when the selector switch is

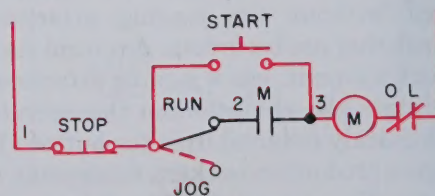
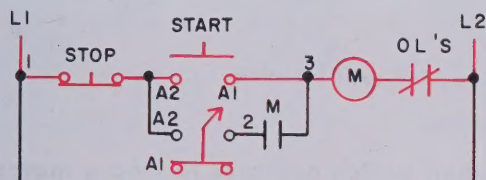


FIG. 47-7 Jogging using a standard duty, two-position selector switch

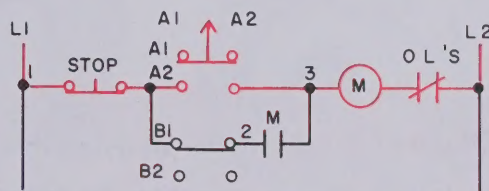
placed in the jog position. The motor is then inched with the start button. Figure 47-8 is the same circuit as that shown in figure 47-7 with the substitution of a heavy-duty, two-position selector switch.



A1	I	
A2		I
	JOG	RUN

FIG. 47-8 Jogging using a selector-switch jog with start button

The use of a selector push button to obtain jogging is shown in figure 47-9. In the jog position, the holding circuit is broken, and jogging is accomplished by depressing the push button.



A1	I			
A2		I		I
B1	I	I		
B2				I
	FREE	DEPRESSED	FREE	DEPRESSED
	RUN		JOG	

FIG. 47-9 Jogging using selector pushbutton

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Why is jogging (inching) included in this section on "Methods of Deceleration"?
2. What is the safety feature of a lock-stop push button?
3. In (A) of figure 47-3, what will happen if both the run and jog push buttons are closed?
4. What will happen if the start and jog push buttons of the circuit shown in figure 47-4 are pushed at the same time?
5. In figure 47-6, what will happen if both jog push buttons are pushed momentarily?
6. Draw an elementary control diagram of a reversing starter. Use a standard duty selector switch with forward, reverse, and stop push buttons with three methods of interlocking.

UNIT 48 *Plugging*

Objectives After studying this unit, the student will be able to:

- Define what is meant by the plugging of a motor
- Describe how a control circuit using a zero-speed switch operates to stop a motor
- Describe the action of a time-delay relay in a plugging circuit
- Describe briefly the action of the several alternate circuits which use the zero-speed switch
- Connect plugging control circuits
- Recommend troubleshooting solutions for plugging problems

Plugging is defined by NEMA as a system of braking, in which the motor connections are reversed so that the motor develops a counter torque which acts as a retarding force. Plugging controls provide for the rapid stop and quick reversal of motor rotation.

Motor connections can be reversed while the motor is running unless the control circuits are designed to prevent this type of connection. Any standard reversing controller can be plugged, either manually or with electromagnetic controls. Before the plugging operation is attempted, however, several factors must be considered including:

1. the need to determine if methods of limiting the maximum permissible currents are necessary, especially with repeated operations and dc motors.
2. the need to examine the driven machine to insure that repeated plugging will not cause damage to the machine.

PLUGGING SWITCHES AND APPLICATIONS

Plugging switches, or zero-speed switches, are designed to be added to control circuits as pilot devices to provide quick, automatic stopping of machines. In most cases, the machines will be driven by squirrel cage motors. If the switches are adjusted properly, they will prevent the direction reversal of rotation of the controlled drive after it reaches a standstill following the reversal of the motor connections. One typical use of plugging switches is for machine tools which must stop suddenly at some point in their cycle of operation to prevent inaccuracies in the work or damage to the machine. Another use is for processes in which the machine must stop completely before the next step of work begins. In this case, the reduced stopping time means that more time can be applied to production to achieve a greater total output.

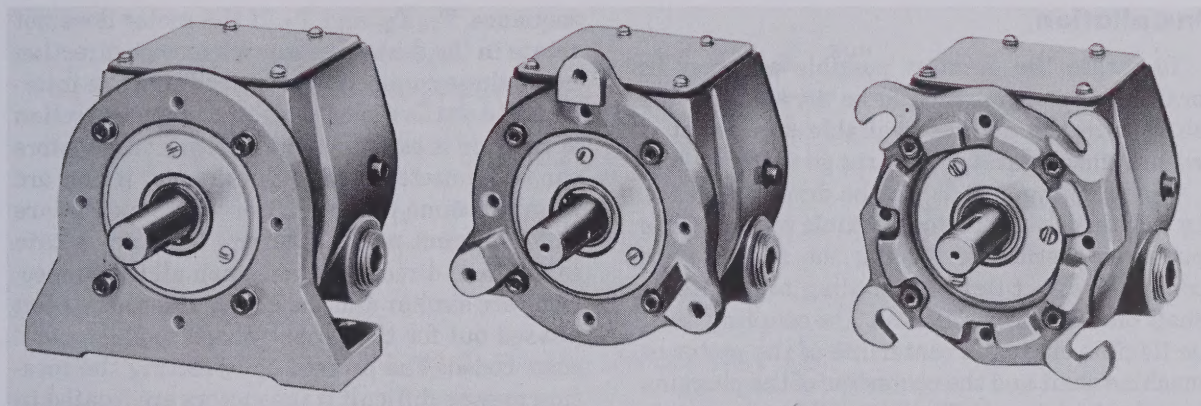


FIG. 48-1 Plugging (zero-speed) switches. Note mounting methods. (Courtesy Allen-Bradley Co.)

Typical plugging switches are shown in figure 48-1. The shaft of a plugging switch is connected mechanically to the motor shaft or to a shaft on the driven machine. The rotating motion of the motor is transmitted to the plugging switch contacts either by a centrifugal mechanism or by a magnetic induction arrangement (eddy current disc) within the switch. The switch contacts are wired to the reversing starter which controls the motor. The switch acts as a link between the motor and the reversing starter. The starter applies just enough power in the reverse direction to bring the motor to a quick stop.

Plugging a Motor to a Stop From One Direction Only

The forward rotation of the motor in figure 48-2 closes the normally open plugging switch contact. When the stop button is pushed, the forward contactor drops out. At the same time, the reverse contactor is energized through the plugging switch and the normally closed forward interlock. Thus, the motor connections are reversed and the motor is braked to a stop. When the motor is stopped, the plugging switch opens to disconnect the reverse contactor. This contactor is used only to stop the motor using the plugging operation; it is not used to run the motor in reverse.

Adjustment

The torque that operates the plugging switch contacts will vary according to the speed of the motor. An adjustable contact spring is used to oppose the torque to insure that the contacts open and close at the proper time regardless of the motor speed. To operate the contacts, the motor must produce a torque that will overcome the spring pressure. The spring adjustment is generally made with screws that are readily accessible when the switch cover is removed.

Care must be exercised to prevent the entry of chips, filings, and hardware into the housing when it is opened. Such material may be attracted to the magnets or hamper spring action. The housing must be carefully cleaned before the cover is removed for maintenance or inspection.

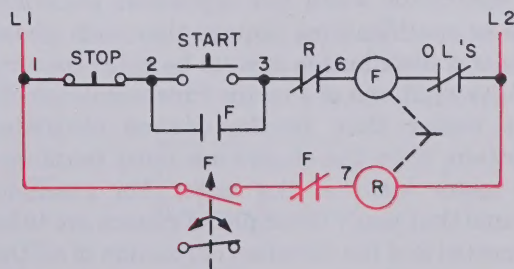


FIG. 48-2 Plugging motor to stop from one direction only

Installation

To obtain the greatest possible accuracy in braking, the switch should be driven from the shaft with the highest available speed that is within the operating speed range of the switch.

The plugging switch may be driven by gears, by a chain drive, or a direct flexible coupling. The preferred method of driving the switch is to connect a direct flexible coupling to a suitable shaft on the driven machine. The coupling must be flexible since the centerline of the motor or machine shaft and the centerline of the plugging switch shaft are difficult to align accurately enough to use a rigid coupling. The switch must be driven by a positive means. Thus, a belt drive should not be used. In addition, a positive drive must be used between the various parts of the machine being controlled, especially where these parts have large amounts of inertia.

The starter used for this type of circuit is a reversing starter that interchanges two of the three motor leads for a three-phase motor, reverses the direction of current through the armature for a dc motor, and reverses the relationship of the running and starting windings for a single-phase motor.

Motor Rotation

Experience shows that there is little way of predetermining the direction of the rotation of motors when the phases are connected externally in proper sequence. This is an important consideration for the electrician and the electrical contractor when the applicable electrical code or specifications require that each phase wire of a distribution system be color coded.

If the shaft end of a motor runs counterclockwise rather than in the desired clockwise direction, then the electrician must reconnect the motor leads at the motor. For example, assume that many three-phase motors are to be connected and the direction of rotation of all the motors must be the same. If counterclockwise rotation is desired, the supply phase should be connected to the motor terminals in the proper

sequence, T_1 , T_2 , and T_3 . If the motor does not rotate in the desired counterclockwise direction using these connections, the leads may be interchanged at the motor. Once the proper direction of rotation is established, the remaining motors can be connected in a similar manner if they are from the same manufacturer. If the motors are from different manufacturers, they may rotate in different directions even when all the connections are similar and the supply lines have been phased out for the proper phase sequence and color coded. The process of correcting the rotation may be difficult if the motors are located in a place that is difficult to reach.

Lockout Relay

The zero-speed switch can be equipped with a lockout relay or a safety latch relay. This type of relay provides a mechanical means of preventing the switch contacts from closing unless the motor starting circuit is energized. The safety feature insures that if the motor shaft is turned accidentally, the plugging switch contacts do not close and start the motor. The relay coil generally is connected to the T_1 and T_2 terminals of the motor. The lockout relay should be a standard requirement for circuits to protect people, machines, and production processes.

PLUGGING WITH THE USE OF A TIMING RELAY

A time-delay relay may be used in a motor plugging circuit, figure 48-3. Unlike the zero-speed switch, this control circuit does not compensate for a change in the load conditions on the motor. The circuit shown in figure 48-3 can be used for a constant load condition once the timer is preset. If the emergency stop button in figure 48-3(A) is pushed *momentarily* and the normally open circuit is *not* completed, the motor will coast to a standstill. (This action is also true of the normal double contact stop button.) If the emergency stop button is pushed to *complete* the normally open circuit of the push button, then

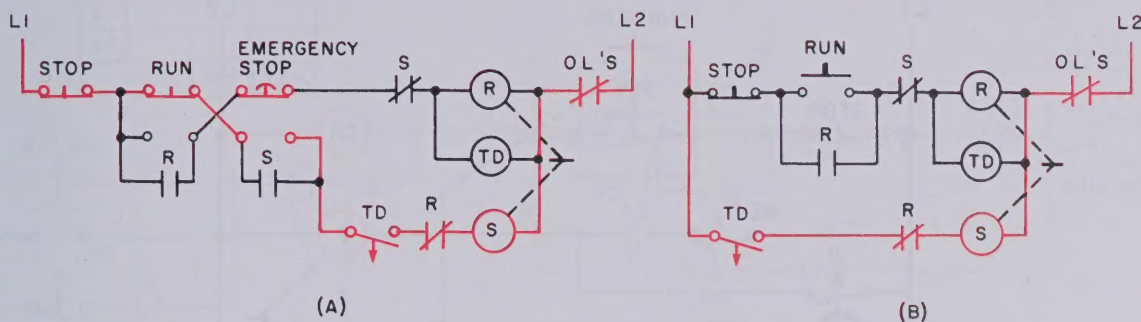


FIG. 48-3 Plugging with time-delay relay

contactor S is energized through the closed contacts (TD and R). Contactor S closes and reconnects the motor leads, causing a reverse torque to be applied. When the relay coil is de-energized, the opening of contact TD can be retarded. The time lag is set so that contact TD opens at or near the point at which motor shaft speed reaches 0 r/min.

ALTERNATE CIRCUITS FOR PLUGGING SWITCH

The circuit in figure 48-4 is used for operation in one direction only. When the stop push button is pressed and immediately released, the motor and the driven machine coast to a standstill. If the stop button is held down, the motor is plugged to a stop.

Using the circuit shown in figure 48-5, the motor may be started in either direction. When the stop button is pressed, the motor can be plugged to a stop from either direction.

The circuit shown in figure 48-6 provides operation in one direction. The motor is plugged to a stop when the stop button is pressed. Jogging is possible with the use of a control relay.

Figure 48-7 shows a circuit for controlling the direction of rotation of a motor in either direction. Jogging in either the forward or reverse direction is possible if control jogging relays are used. The motor can be plugged to a stop from either direction by pressing the stop button.

The circuit in figure 48-8 provides control in either direction using a maintained contact selector switch with forward, off, and reverse positions. The plugging action is available from either direction of rotation when the switch is

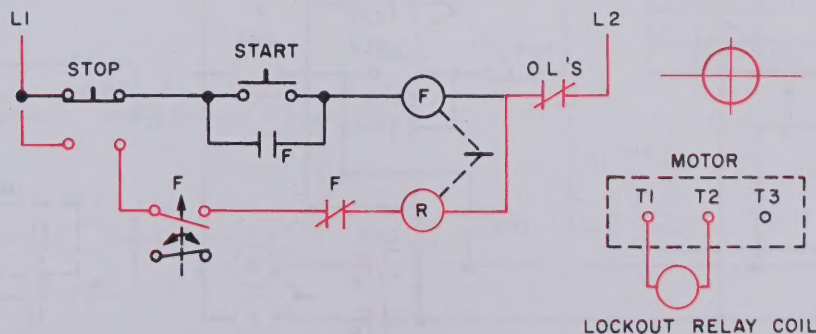


FIG. 48-4 Holding stop button will stop motor in one direction

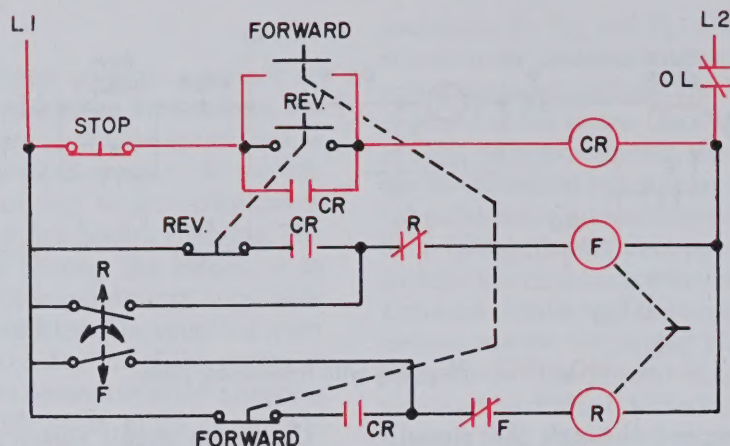


FIG. 48-5 In this circuit, pressing stop button stops motor in either direction

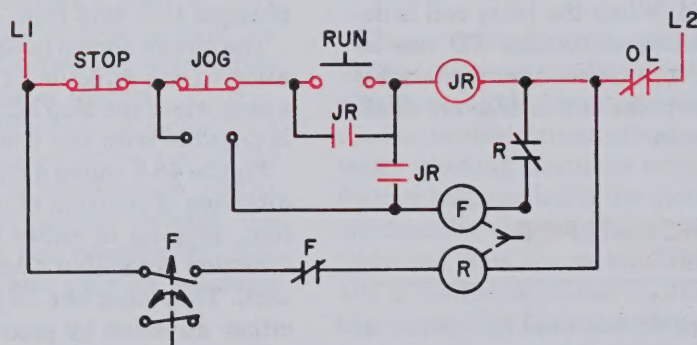


FIG. 48-6 Pressing stop button will stop motor in one direction

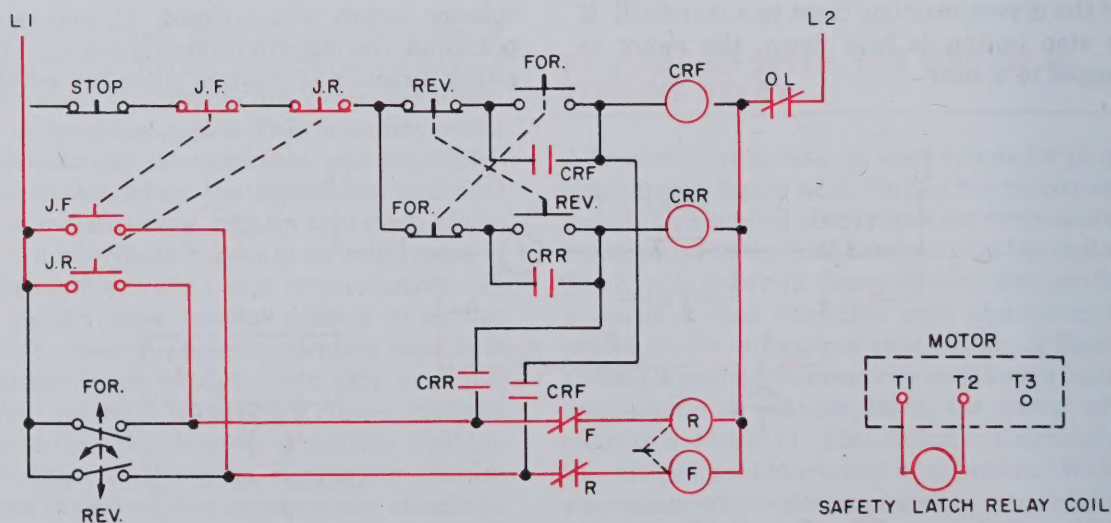


FIG. 48-7 Use of control jogging relays will stop motor in either direction

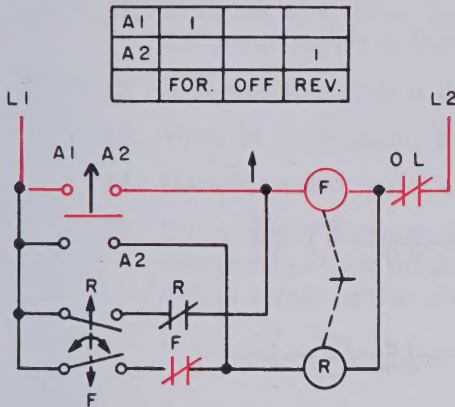


FIG. 48-8 Using the maintained contact selector switch

turned to the off position. Low-voltage protection is not provided with this circuit.

The circuit in figure 48-9 allows motor operation in one direction. The plugging switch is used as a speed interlock. The solenoid, or coil F, will not operate until the main motor reaches its running speed. A typical application of this circuit is to provide an interlock for a conveyor system. The feeder conveyor motor can not be started until the main conveyor is operating.

ANTIPLUGGING PROTECTION

Antiplugging protection, according to NEMA, is obtained when a device prevents the application

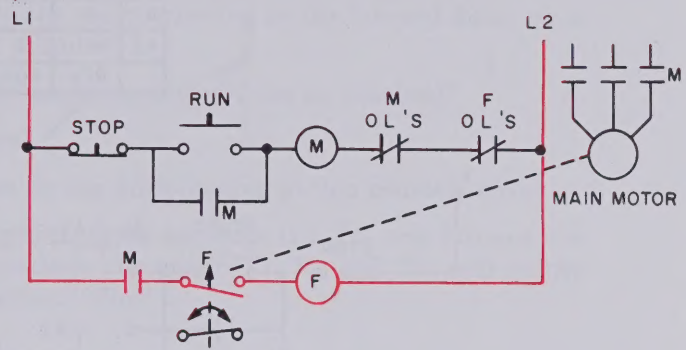


FIG. 48-9 Using plugging switch as speed interlock

of a counter torque until the motor speed is reduced to an acceptable value. An antiplugging circuit is shown in figure 48-10. With the motor operating in one direction, a contact on the antiplugging switch opens the control circuit of the contactor used to achieve rotation in the opposite direction. This contact will not close until the motor speed is reduced. Then the other contactors can be energized.

Alternate Antiplugging Circuits

The direction of rotation of the motor is controlled by the motor starter selector switch, figure 48-11. The antiplugging switch completes the reverse circuit only when the motor slows to a safe, preset speed. Undervoltage protection is not available.

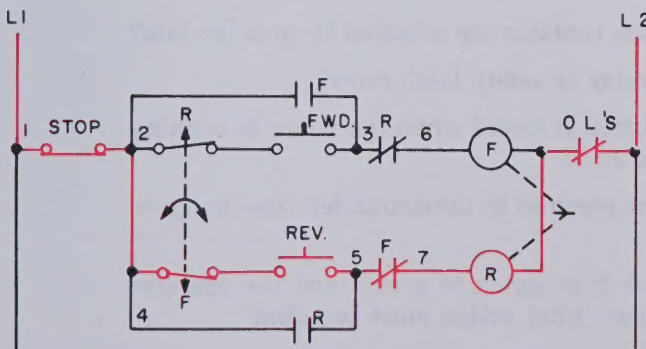


FIG. 48-10 Antiplugging protection; the motor is to be reversed but not plugged

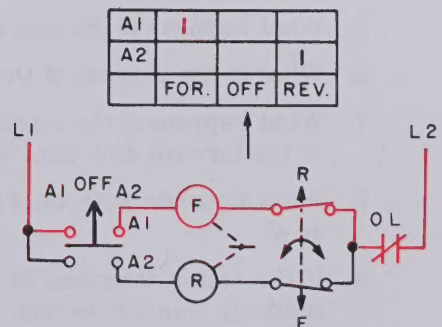


FIG. 48-11 Antiplugging with rotation direction selector switch

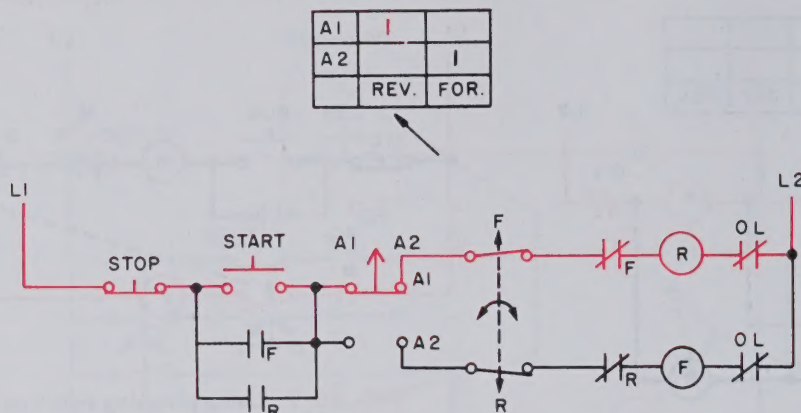


FIG. 48-12 Antiplugging circuit using a selector switch and providing low-voltage protection

In figure 48-12, the direction of rotation of the motor is selected by using the maintained contact, two-position selector switch. The motor is started with the push button. The direction

of rotation can not be reversed until the motor slows to a safe, preset speed. Low-voltage protection is provided by a three-wire, start-stop, push-button station.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. In figure 48-2, what is the purpose of normally closed contact (F)?
2. Can a time-delay relay be used satisfactorily in a plugging circuit? Explain.
3. In what position must a plugging switch be mounted? Explain.
4. What is the preferred method of connecting the plugging switch to the motor or the driven machine?
5. What happens if the zero-speed switch contacts are adjusted to open too late?
6. What is the purpose of the lockout relay or safety latch relay?
7. What happens if the reverse push button is closed when the motor is running in the forward direction, as in figure 48-5?
8. What alternate methods of stopping are provided by the circuit described in figure 48-4?
9. If the motor described in figure 48-6 is plugging to a stop and the operator suddenly wants it to inch ahead or run, what action must be taken?
10. In figure 48-7, is it necessary to push the stop button when changing the direction of rotation? Explain your answer.

11. In figure 48-8, what happens to the motor running in the forward direction if the power supply is lost for 10 minutes?
12. In figure 48-9, how is the feeder motor protected from an overload?
13. What is antiplugging protection?
14. During normal operation, when do the antiplugging switch contacts close?
15. If the supply lines are in the proper phase sequence (L1, L2, and L3) and are connected to their proper terminals on the motor (T1, T2, and T3), will all the motors rotate in the same direction? Why?

UNIT 49 Electric Brakes

Objectives After studying this unit, the student will be able to:

- Describe the general operation of electric brakes, both ac operated and dc operated
- State the advantages of dc shunt wound brakes over ac-operated brakes
- Describe the function of typical braking circuits for hoists and cranes
- Connect motors and braking controllers
- Recommend troubleshooting solutions for electric brake problems

Many modern industrial processes require very powerful motors running at increased speeds. These motors must frequently be stopped in a shorter time than can be obtained by disconnecting the power from the motor. When machines require one or more motors and more precise control, and there is less time available to wait for the machines to coast to a standstill, then it is even more important to provide faster stopping methods.

Since the early 1900s, *electric brakes* have been in use. These are also known as *magnetic brakes*, *friction brakes* and *mechanical brakes*. An electric brake consists of two friction surfaces, or shoes, which can be made to bear on a wheel on the motor shaft, figure 49-1. Spring tension holds the shoes on the wheel. Braking is achieved because of the friction between the shoes and the wheel. A solenoid mechanism is used to release the shoes.

In a magnetically operated brake, the shoes are held in a released position by a magnet as long as the magnet coil is energized. However, if a pilot device interrupts the power, or there

is a power failure, then the brake shoes are applied instantly to provide a fast, positive stop.

The coil leads of an alternating-current magnetic brake normally are connected directly

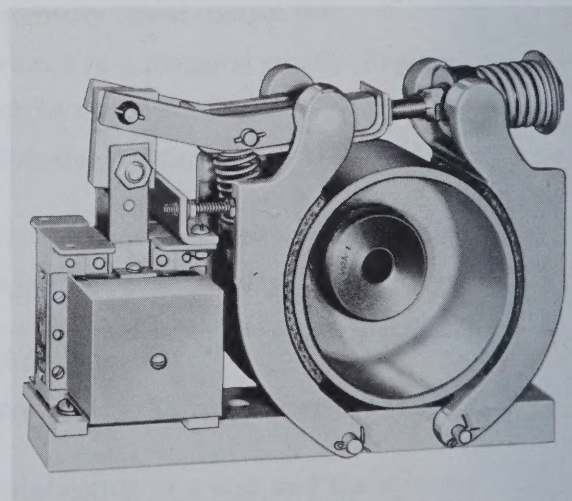


FIG. 49-1 Solenoid brake used on machine tools, conveyors, small hoists, and similar devices (Courtesy EATON Corp., Cutler-Hammer Products)

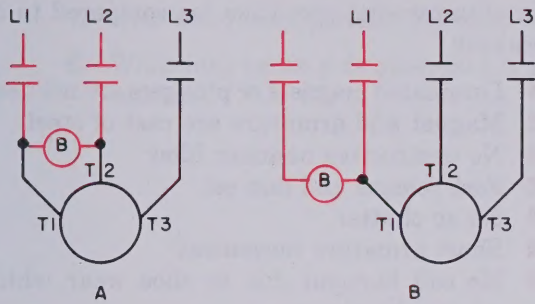


FIG. 49-2 Ac brake coil connections for across-the-line starting. Control relays and contactors also are used to control magnetic brakes

to the motor terminals, figure 49-2. If a reduced-voltage starting method is used, the brake coil should be connected to receive full voltage.

Magnetic brakes provide a smooth braking action. This feature makes them suitable for high-inertia loads. Since these brakes apply and remove the braking pressure smoothly in either direction, they are often used on cranes, hoists, elevators, and other machinery where it is desirable to limit the shock of braking.

This brake is operated by a vertically mounted torque motor. When power is applied to the brake torque motor, the shaft of the motor turns and lifts the operating lever of a ball jack to release the brake. When the brake is fully released, the torque motor is stalled across the line. When power is released from the brake, a heavy compression spring counteracts the jack lever so that the brake is applied quickly.

MAGNETIC DISC BRAKES

Disc brakes generally can be installed wherever shoe brakes are used. Disc brakes can also be installed where appearance and available space prohibit the use of shoe brakes.

Magnetic disc brakes are used on machine tools, cranes, hoists, conveyors, printing presses, saw mills, index mechanisms, overhead doors, and other installations. The control adjustments of the torque and wear of disc brakes are simi-

lar to those for shoe brakes. A disc brake is a self-enclosed unit that is bolted directly to the end bell of the motor. (This end bell operates on the motor shaft.) The braking action consists of pressure released by a solenoid and applied by a spring on the sides of a disc or discs.

DC MAGNETIC BRAKES

The construction of dc magnetic brakes is similar to that of ac shoe brakes. For dc magnetic brakes, however, the operating coils are shunt wound for across-the-line connections and series wound for connecting in series with dc motor armatures.

Shunt-wound brakes pick up at approximately 80 percent of the rated voltage and drop out about 60%. Series-wound brakes pick up (release) at about 40 percent of the full load current of the motor and drop out (set) when the current reaches 10 percent of the full load value.

The brake linings for dc magnetic brakes are similar to those for ac brakes. The linings are made of molded or woven asbestos with high friction resistance. They are bonded or riveted to steel backplates. Brakes range in size from approximately one inch to 30 inches in diameter. Large diameter shunt-wound brakes are available with a relay and protective resistor to permit operation at high speed. Brakes with smaller diameters pick up and drop out quickly without this added feature. The large diameter, high-speed brakes release quickly. When the armature closes, the protective resistor is inserted in the circuit. This action reduces the holding current to a low value and keeps the coil cooler. As a result, the brake sets quickly. High-speed brakes are suitable for any duty. They can be operated on alternating current if a rectifier unit is added.

The operation of dc magnetic brakes may be sluggish due to the induction present, unless the manufacturer has attempted to overcome it in order to speed the brake operation. The following list gives advantages of the use of dc brakes

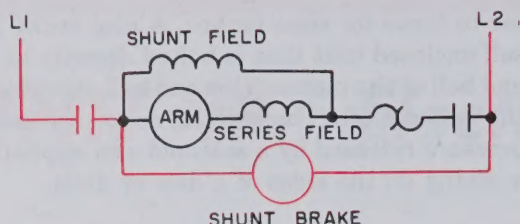
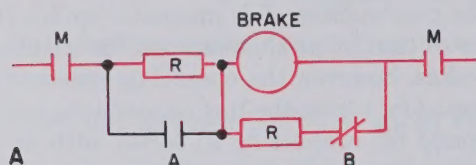


FIG. 49-3 Dc shunt brake connections with motor connections



	MAXIMUM LOWER	INTERMED LOWER	SLOW LOWER	OFF
M	I	I	I	
A	I			
B			I	I

FIG. 49-4 Varying friction braking

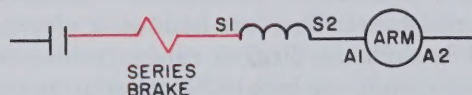


FIG. 49-5 Series brake connected with series motor

for shunt-wound operation (as compared to ac brakes):

- Laminated magnets or plungers are not used
- Magnet and armature are cast of steel
- No destructive hammer blow
- Fast release and fast set
- No ac chatter
- Short armature movement
- No coil burnout due to shoe wear which affects the air gap

Figure 49-3 shows the connection of a dc brake in a circuit which does not allow armature regeneration through the brake coil. As a result, the brake is prevented from setting.

Figure 49-4(A) shows a shunt brake control circuit. (This circuit is a small portion of a crane hoist elementary diagram.) The target table in figure 49-4(B) lists the contacts which are closed for different crane-lowering operations. Note how the brake is weakened by the use of resistors in series and in parallel.

Series-wound brakes generally are used with series motors, figure 49-5, and must have the same full-load current rating as the motor. The brakes must be properly sized for their loads also. Series-wound brakes may be used for heavy hoist applications and for many metal processing applications, such as steel mill drives and conveyors.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Why are magnetic brakes used?
2. How do electric brakes operate?
3. When an ac reduced-voltage starter is used, how should the electric brakes be wired for release?
4. Why should protective resistors be provided on coils for high-speed shunt brakes?
5. In figure 49-4, which contacts are closed when the brake coil receives full voltage?
6. What precautions must be taken when matching a series-wound brake to a motor?

7. How are electric brakes adjusted in general?
8. What may cause a de-energized brake to slip under load with maximum spring tension?

UNIT 50 *Dynamic and Regenerative Braking*

Objectives After studying this unit, the student will be able to:

- Describe what is meant by the process of dynamic and regenerative braking
- Describe the general series of controller connections that can be made to obtain hoisting, lowering, and braking operations at different speeds
- List several advantages of dynamic and regenerative braking
- Describe three methods of providing dynamic braking for light-duty equipment
- Explain how dynamic braking can be provided for a synchronous motor
- Connect motors and dynamic braking controllers
- Recommend troubleshooting solutions for dynamic braking problems

A motor can be stopped by disconnecting it from the power source. A faster means of stopping a motor is achieved if the motor is reconnected so that it acts as a generator. This method of braking is called *dynamic braking*.

When a dc motor is reconnected so that the field is excited and there is a low resistance path across the armature, the generator action converts some of the mechanical energy of rotation to electrical energy (as heat in discharge resistors). The result is that the motor slows down sooner. However, as the motor slows down, the generator action decreases, the current decreases, and the braking lessens. This means that *a motor cannot be stopped by dynamic braking alone*.

A motor driving a crane hoist will let the load down too quickly if it is simply disconnected from the line. Some kind of braking is essential. A slight variation of the dynamic braking

method just described works very well for this situation.

A series motor is used because of its characteristics for lifting and moving heavy loads. An electric brake connected in the line keeps the motor shaft from turning when there is no line current. To stop the hoist, therefore, it is necessary only to open the circuit to the motor.

To lower a load, the motor is reconnected as a shunt generator. That is, the series field is connected in series with a resistor. The combination is then connected directly across the line. Other possible connection schemes for series motors may be used.

The armature may be connected to a resistance to obtain dynamic braking as described earlier. It is more satisfactory, however, to connect the armature to the line as well. As a result, some of the mechanical energy is put back in the line as electrical energy. This means that the resis-

tors are not required to handle as much heat. It also saves electrical energy. This process is called *regenerative braking*.

Regenerative braking is available on nearly all dc solid-state adjustable speed drives. The solid-state system provides a very precise controlled stop for those applications in which such control is essential. Unlike the nonregenerative system, which provides a coasting stop, the regenerative system uses the motor's braking force for a more controlled, faster stop. Where such precise control is not essential, and the additional cost of the regenerative system is not economically practical, a nonregenerative system can be used. With a regenerative system, there are twice as many SCR cell stacks within the same panel enclosure, such as those used in the dc solid-state adjustable speed drives.

In an electromagnetic system, the control is moved from the hoisting or lowering positions to the stop position, the load should be slowed by dynamic braking before the mechanical brake takes hold. In this way, wear is reduced on the mechanical brake bands.

The schematic diagrams in figure 50-1 show how the controller connections can be changed to obtain the hoisting, lowering, and braking operations at different speeds. To simplify these diagrams, the control contactors and other components have not been shown.

For maximum hoist operation, figure 50-1(A), the dc series motor and the brake receive the full line voltage and the maximum current.

In the intermediate hoist position, figure 50-1(B), the motor is slowed when a resistor is added in series with the motor. The resistor is not large enough to allow the brake to set or drag, however.

In the slow hoist position, figure 50-1(C), some current is bypassed around the motor by the parallel resistor. As a result, the motor is slowed and the brake receives enough current to remain open.

In the lower positions, figures 50-1(D) through 50-1(F), regeneration back into the supply system is possible. The dissipating resistor regu-

lates the field and the brake. The brake is de-energized in the *Off* position with maximum braking pressure applied.

Dynamic braking is a simple and safe method of emergency or safety braking. Since the motor is converted to a self-exciting generator to provide the slowing action, the braking does not

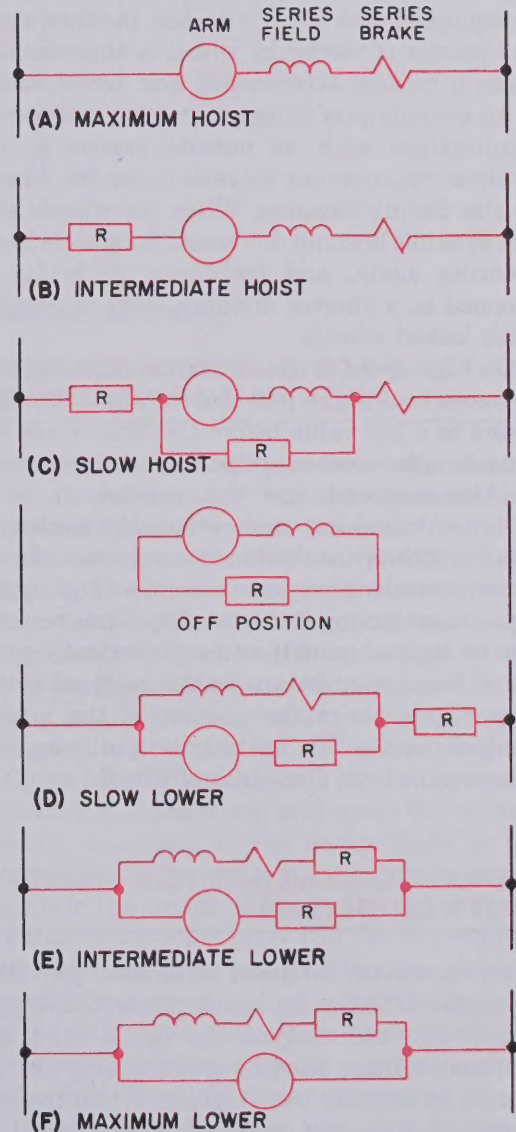


FIG. 50-1 Reconnecting a crane controller for different operations

depend on an outside source of power. Machines operating at higher speeds have braking problems not found with lower operating speeds. The need for a more rapid initial slow-down is essential if accidents are to be avoided. Dynamic braking is applied in about one-fifth the time required to set the majority of shunt brakes.

Due to space limitations, some drives cannot be equipped with electric brakes. In other cases, the inertia of the brake wheel is objectionable since it retards acceleration and deceleration.

An advantage of dynamic braking is shown in applications such as outside cranes or ore bridges where wet or icy rails cause the wheels to slip during stopping. When the wheels slip, the dynamic braking decreases, the wheels begin rotating again, and the crane or bridge is stopped in a shorter distance than is possible with locked wheels.

On high-speed drives, it is recommended that dynamic braking be provided to reduce the drive speed to a low value before the brakes are set. An example is an ore bridge trolley where severe braking may endanger the operator.

Dynamic braking can be started by track-type limit switches installed in the end zones of overhead traveling cranes. Cranes and other equipment having this type of dynamic braking can be stopped quickly and automatically when there is a power failure or the overload relays trip, regardless of the position of the master control handle. The braking torque is equally effective in both directions of travel.

DYNAMIC BRAKING FOR LIGHT-DUTY EQUIPMENT

There are many different methods of providing dynamic braking for small production equipment. For the diagram in figure 50-2, the reduced voltage starting mechanisms are not shown to simplify the diagram. When the stop button is depressed, normally closed contact A completes the braking circuit through the braking resistor. Note that the shunt field must be

energized for both deceleration and acceleration. Full field strength must be available for both. If a rheostat is used in the shunt field for speed control, the resistance is cut out manually or automatically. The disconnect switch should be open when the machine is not in service.

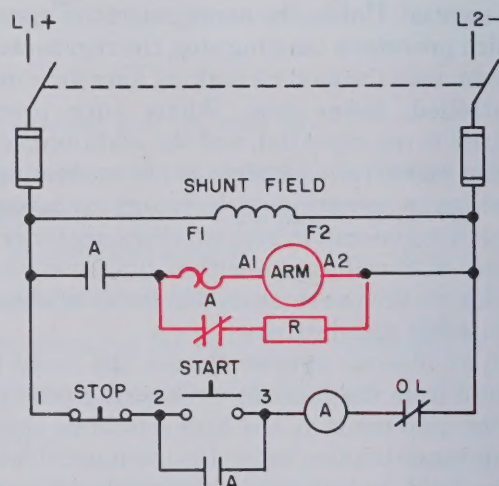


FIG. 50-2 Dynamic braking connections on motor starter

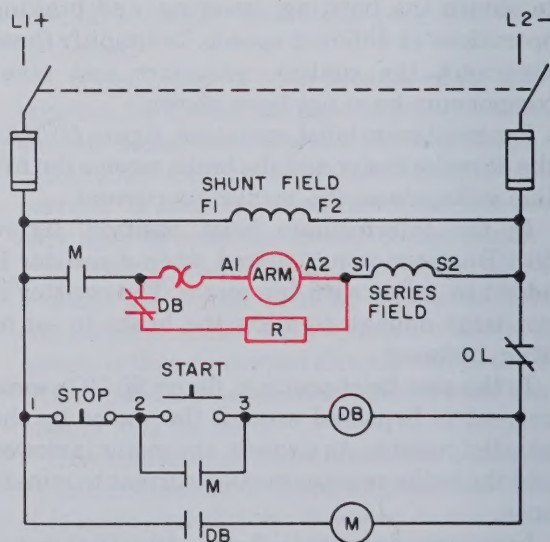


FIG. 50-3 Dc motor starter modified with dynamic braking

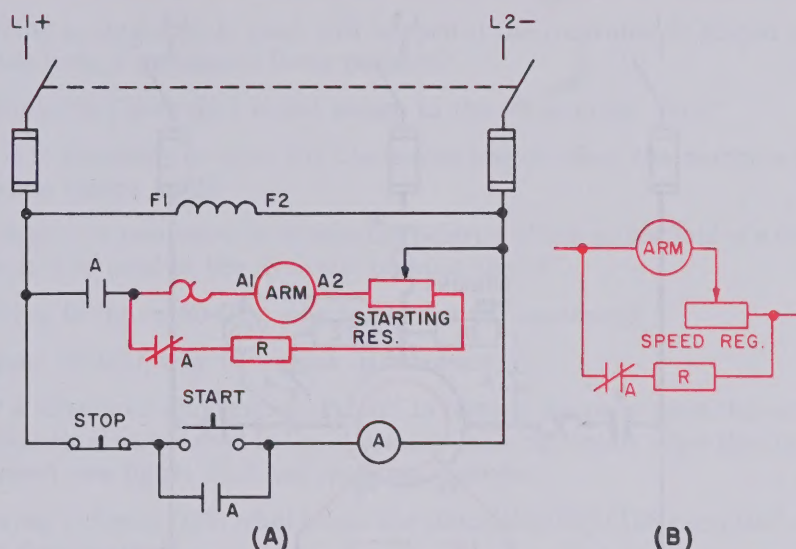


FIG. 50-4 Using the starting resistance for braking

Figure 50-3 is a modification of figure 50-2. The circuit in figure 50-3 insures that the braking resistor is not connected across the line. If the series field is used in the braking circuit, the dc compound motor characteristic (differential or cumulative) must be determined. If it is a cumulative compound motor, then the series field current direction must be reversed when it is used in the braking circuit. Automatic operation can be provided for such an action.

Figure 50-4(A) shows a diagram for a braking circuit which uses the starting resistance for braking. This circuit may be satisfactory for a number of situations if the starting and stopping cycle does not exceed the capacity of the resistors. A speed regulator is designed for continuous duty operation. The fixed resistor (R) in the braking circuit is a current-limiting resistor. It may not be required when a speed regulator is used because of the increased capacity. Figure 50-4(B) shows the control circuit for adjusting the braking speed. Resistor (R) is a current-limiting resistor which prevents a short circuit on the armature. The value of R is selected so maximum braking speed is obtained when all resistance is cut out by the speed regulator.

DYNAMIC BRAKING FOR A SYNCHRONOUS MOTOR

Because of the similarity in the construction of a synchronous motor and an alternator (ac generator), a synchronous motor can be reconnected as an alternator to provide faster stopping. The kinetic energy of the rotor and the driven machine is converted to electrical energy by generator action and then to heat by the dissipating resistors. A method developed by the author for the dynamic braking of a synchronous motor is illustrated in the elementary diagram of figure 50-5. When the start button is pressed, contactor A is energized and opens the resistor circuits connected to the motor leads in the control panel. Contactor A energizes coil M to maintain the circuit and start the motor across the line. Time-delay relay coil TD is energized and its timing cycle begins. After the motor is brought up to speed by the windings in the rotor, the normally open, delay-in-closing contact (TD) energizes the dc contactor (B) to supply current to the field. The field discharge resistor circuit is opened as well. When the stop button is pressed, the ac supply is removed from the stator. The timer coil, however, remains energized so

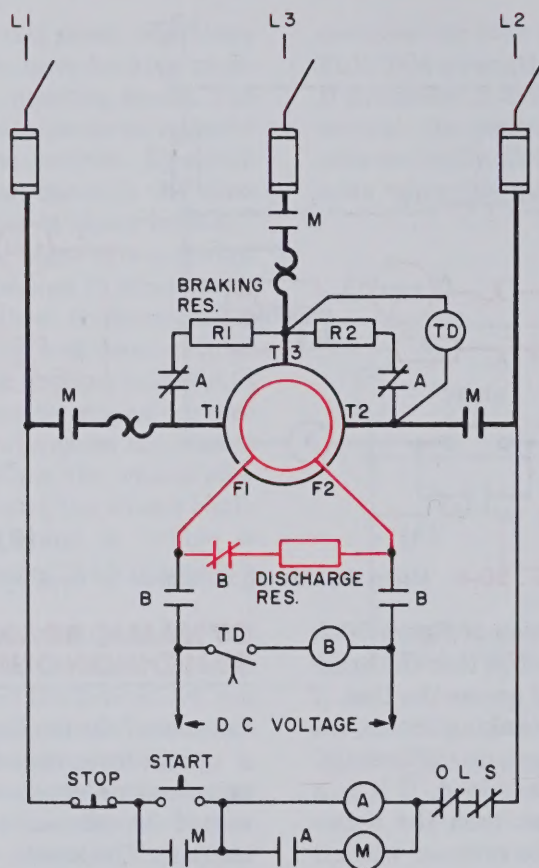


FIG. 50-5 Dynamic braking applied to synchronous motor

that its contact remains closed. As a result, direct current continues to flow through the rotor. As the rotation continues, the magnetic lines of force of the rotor cut across the stator windings to generate a current. This current keeps the timing relay contact (TD) closed. The contact remains closed as long as the rotor maintains a voltage drop across the braking resistor

(R2). Direct current is removed automatically from the rotor when it is almost at a standstill. This timed, semiautomatic method of synchronizing was selected to illustrate this method of braking for reasons of simplicity. With a simple modification, it is readily adaptable to any completely automatic, synchronizing control system.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. After dynamic braking occurs, why is a mechanical brake generally necessary?
2. What becomes of the energy used to brake the motor dynamically for the two methods described?

3. Referring to figure 50-1, what will happen if the controller is placed in the off position from a maximum lower position?
4. The brake in figure 50-1 is not shown in the off position. Why?
5. Why is it necessary to open the disconnect switch when the machine is not in operation (figure 50-2)?
6. Why may it be necessary to reverse the polarity of the series field of a compound motor if it is used in the dynamic braking circuit?
7. Referring to figure 50-4(B), why is resistor (R) necessary?
8. In figure 50-4(A), why is resistor (R) necessary?
9. Draw a schematic diagram of a circuit to reverse the polarity of the series field of a compound motor used in the automatic braking circuit when the stop button is pressed (see figure 50-3 and question 6 above).
10. Referring to figure 50-5, what keeps the time-delay coil (TD) energized after coil (M) is de-energized?
11. Design a shunt field circuit for figure 50-2 to include
 - a. a rheostat for motor speed control
 - b. automatic removal of the rheostat when the stop button is pushed

UNIT 51 *Electric and Electronic Braking*

Objectives After studying this unit, the student will be able to:

- Describe the method of operation of a typical electric braking controller
- List advantages of the use of an electric brake on an ac induction motor
- Connect electric braking controllers
- Recommend troubleshooting solutions for electric braking problems

APPLICATION

As a powerful production machine slowly coasts to a stop, the operator is idle. Work is not being accomplished by either the operator or the machine. This slow stop may be cited as a safety hazard under the occupational safety laws. There is, however, a simple, economical, and effective way to eliminate this type of stop to improve the

safety and efficiency of the equipment. An all electric braking controller provides an effective brake for a standard drive, ac squirrel cage motor. It will stop ac motor-driven equipment as fast as it takes to reach full speed. Operation is smooth, noise-free and automatic. This type of controller is designed to stop motors driving high-inertia loads such as roving or spinning frames. Electric brakes can be used with conveyors, machine tools, woodworking machines, textile machinery, rubber mills, and processing machinery.

Electric and electronic braking controllers, figure 51-1, can be installed on new or existing machines. These controllers have several advantages over conventional brakes. For example, it is sometimes difficult to install conventional electro-mechanical brakes on existing equipment without extensive rebuilding. Mechanical brakes also require extensive mechanical maintenance, adjustment, and periodic replacement of worn parts.

Figure 51-2 shows an electronic braking control that can be added to an existing motor starter.

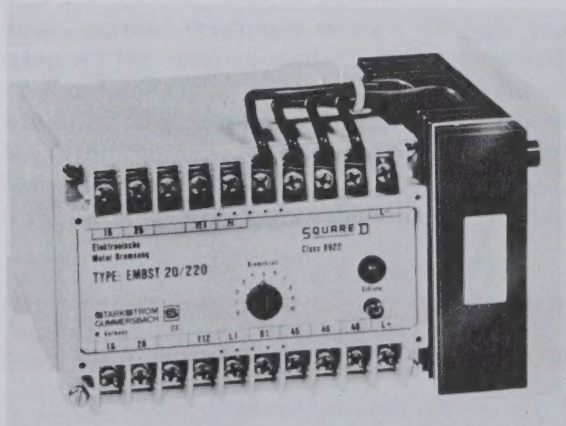


FIG. 51-1 Solid-state braking control for starting and braking (Courtesy Square D Company)

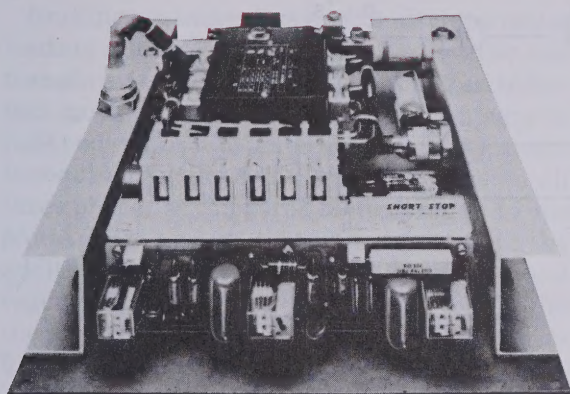


FIG. 51-2(A) Electronic motor brake (Courtesy Ambi-Tech Industries, Hillsdale, NJ)

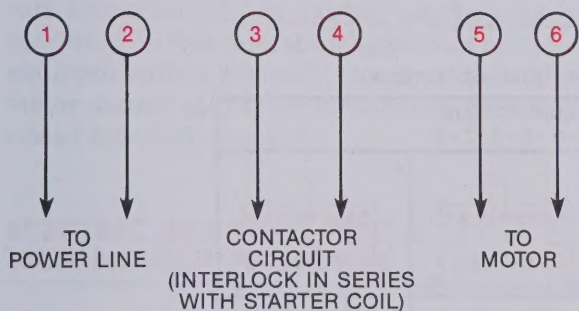
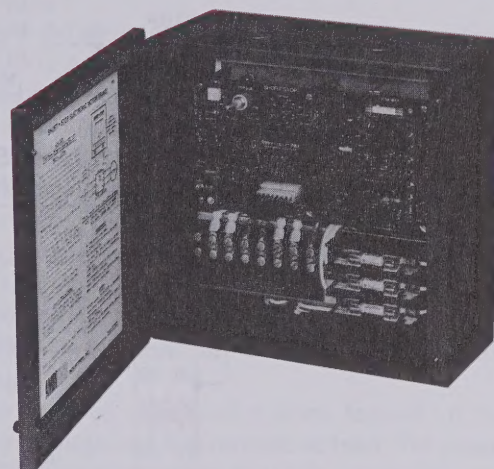


FIG. 51-2(B) Typical connections for an electronic brake shown in figure 51-2(A)

OPERATION

The principle of electric braking can be applied to standard ac squirrel cage or wound-rotor motors. When a motor is to be stopped, direct current is applied to one or all of the three phases of the motor after the ac voltage is removed. There is now a stationary dc field in the stator instead of an ac rotating field. As a result, the motor is braked quickly and smoothly to a standstill. An electric braking controller provides a smoother positive stop because the braking torque decreases rapidly as the speed

approaches zero. Tapped resistors are sometimes used to adjust the braking torque. Controlled SCRs are also used.

Three-phase electric braking improves the efficiency of stopping and reduces the heat buildup in the motor as compared to single-phase braking.

One brake stop is equivalent to a normal start. This means that there must be a reduction in the allowable number of starts that can be made without overheating the motor.

CONSTRUCTION

A self-contained transformer and rectifier provide the direct current required for braking. An adjustable timer is used to provide dependable timing of the braking cycle. A standard reversing starter can be used to supply power to the motor: ac during normal operation and dc during braking.

Terminal blocks are available for motor and control connections. Taps on current-limiting resistors provide a means of adjusting the braking torque over a wide range. Controllers consisting of braking units only can be obtained for use with existing motor starters.

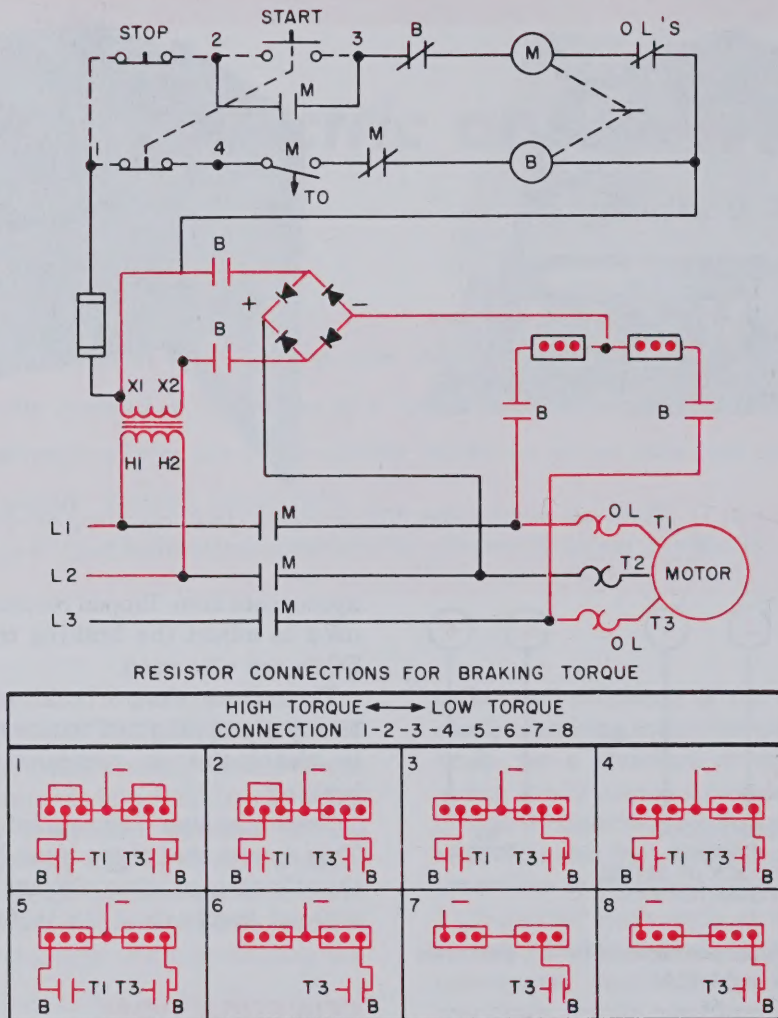


FIG. 51-3 Typical line diagram and resistor connections for an electric braking circuit

SEQUENCE OF OPERATION OF AN ELECTRIC BRAKING CIRCUIT

Figure 51-3A is the schematic diagram of a typical electric braking circuit. When motor starter M is energized, the motor operates as soon as the start button closes. The normally closed contact of the start button insures that braking contactor B is de-energized before the motor is connected to the ac supply.

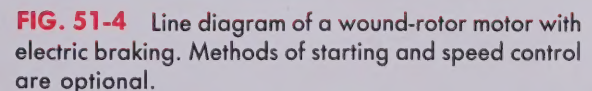
While M is energized, its normally closed interlock contact is open and its normally open time-delay contact is closed. When the stop button is pressed, M drops out. When interlock M recloses, braking contactor B is energized. B remains energized until the time delay contact (M) times open (time delay after de-energized). This timing contact is adjustable and should be set so that contactor B drops out as soon as the motor comes to a complete stop.

Dc and ac supplies must not be connected to a motor at the same time. The motor starter and braking contactor must have adequate interlocks. It is recommended that the motor starter always be included as an integral unit with the brake. If a braking unit only is applied to a separate motor starter, mechanical interlocking is sacrificed. In this case, the start button must be equipped with a normally closed contact. The motor starter also must have extra, normally closed interlock contacts.

Figure 51-4 illustrates a method of braking an induction motor developed under the direction of the author. Although any method of starting can be used, across-the-line starting is shown in figure 51-4 for simplicity. Speed control methods are optional for wound-rotor motors. The circuit in the figure shows that the secondary resistors are eliminated and the slip rings are connected together.

lock M. Ac is removed from the stator by contacts M. Dc is applied by contacts B to establish a "stationary" magnetic field. A rapid deceleration of the rotor results.

The braking speeds of motors depend on the motor ratings and the connected load. For example, a one-horsepower motor with a heavy inertia load, such as a flywheel or conveyor, can be stopped easily in about one second or less if necessary. A 125-horsepower, slow-speed motor



can be stopped, if necessary, in about two or three seconds.

Do such sudden stops harm the motor or the driven equipment? The effect of stopping by this method is much less pronounced than when a mechanical friction brake is used. The braking

action of an electric brake is cushioned and resilient, somewhat like moving a block of steel with a band of rubber. Maximum braking occurs at about 15 to 20 percent of the rated motor speed. Braking tapers off near zero motor speed, resulting in a smooth stop.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Why does three-phase braking reduce motor heating as compared to single-phase braking?
2. Differentiate between the ac and dc magnetic fields applied to an induction motor stator.
3. Electric braking can be applied to what type of ac motor?
4. Why is electric braking smooth and resilient?
5. Braking current is passed through overload heaters; however, the overload control circuit contacts are in the ac starting circuit. How does this protect the motor?
6. How often can a motor be stopped using electric braking?
7. Explain why there is no danger of the motor reversing after it is braked to a stop.

SECTION ELEVEN

MOTOR DRIVES

- UNIT 52** Direct Drives and Pulley Drives
- UNIT 53** Gear Motors
- UNIT 54** Variable Frequency Mechanical Drives
- UNIT 55** AC Adjustable Frequency Solid-State Drives
- UNIT 56** Magnetic Clutch and Magnetic Drive
- UNIT 57** DC Variable Speed Control—Motor Drives
- UNIT 58** Programmable and Motion Control
- UNIT 59** Motor Startup and Troubleshooting Basics

UNIT 52 Direct Drives and Pulley Drives

Objectives After studying this unit, the student will be able to:

- State the advantages of direct and pulley drives
- Install directly coupled motor drives and pulley motor drives
- Check the alignment of the motor and machine shafts, both visually and with a dial indicator
- Install motors and machines in the proper positions for maximum efficiency
- Calculate pulley sizes using the equation:

$$\frac{\text{Drive revolutions per minute}}{\text{Driven revolutions per minute}} = \frac{\text{Driven Pulley Diameter}}{\text{Drive Pulley Diameter}}$$

DIRECTLY COUPLED DRIVE INSTALLATION

The most economical speed for an electrical motor is about 1800 revolutions per minute. Most electrically driven constant speed machines, however, operate at speeds below 1800 r/min. These machines must be provided with either a high-speed motor and some form of mechanical speed reducer, or a low-speed, directly coupled motor. Electronic controlled drives are available, but the expense sometimes exceeds the need.

Synchronous motors can be adapted for direct coupling to machines operating at speeds from 3600 r/min to about 80 r/min, with horsepower ratings ranging from 20 to 5000 and above. It has been suggested that synchronous motors are less expensive to install than squirrel cage motors if the rating exceeds one hp. However,

this recommendation considers only the first cost. It does not take into account the higher efficiency and better power factor of the synchronous motor. When the motor speed matches the machine input shaft speed, a simple mechanical coupling is used, preferably a flexible coupling.

Trouble-free operation can usually be obtained by following several basic recommendations for the installation of directly coupled drives, and pulley or chain drives. First, the motor and machine must be installed in a level position. When connecting the motor to its load, the alignment of the devices must be checked more than once from positions at right angles to each other. For example, when viewed from the side, two shafts may appear to be in line. When the same shafts are viewed from the top, as shown in figure 56-1, it is evident that the motor shaft is at an angle to the other shaft. A dial indicator

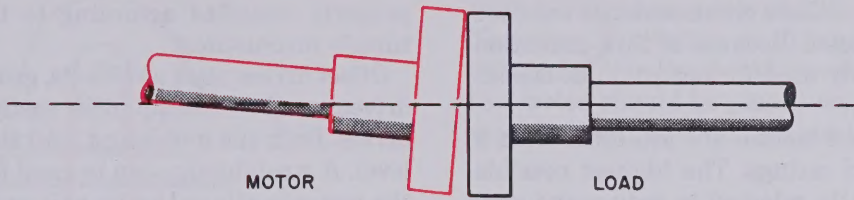


FIG. 52-1 Every alignment check must be made from positioning ninety degrees apart, or at right angles to each other

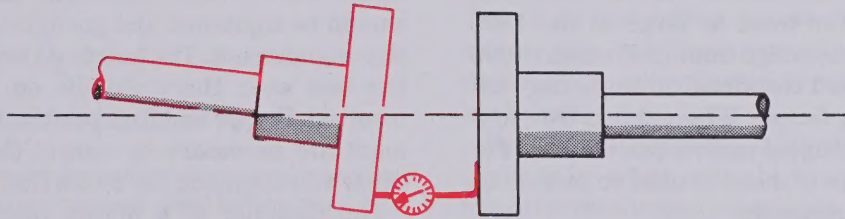


FIG. 52-2 Angular check of direct motor couplings

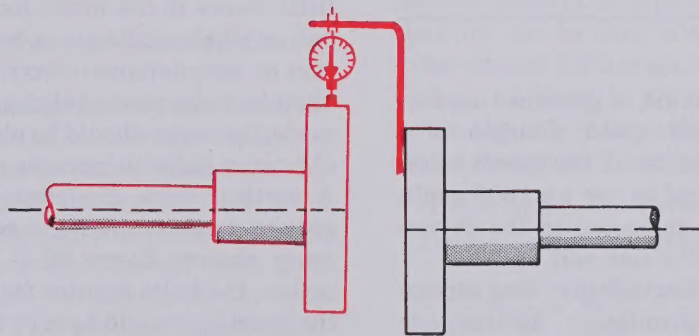


FIG. 52-3 Axis alignment of direct motor couplings

should be used to check the alignment of the motor and the driven machinery, figure 52-2. If a dial indicator is not available, a feeler gauge may be used.

During the installation, the shafts of the motor and the driven machine must be checked to insure that they are not bent. Both machine and motor should be rotated together, just as they rotate when the machine is running, and then rechecked for alignment. After the angle of the shafts is aligned, the shafts may appear to share the same axis. However, as shown in figure 52-3, the axes of the motor and the driven machine may really be off center. When viewed again

from a position ninety degrees away from the original position, it can be seen that the shafts are not on the same axis.

To complete the alignment of the devices, the motor should be moved until rotation of both shafts shows that they share the same axis when viewed from four positions spaced ninety degrees apart around the shafts. The final test is to check the starting and running currents with the connected load to insure that they do not exceed specifications.

There are several disadvantages to the use of low-speed, directly coupled induction motors. They usually have a low power factor and low

efficiency. Both of these characteristics increase electric power costs. Because of this, induction motors are rarely used for operation at speeds below 500 r/min.

Constant speed motors are available with a variety of speed ratings. The highest possible speed is generally selected to reduce the size, weight, and cost of the motor. At five horsepower, a 1200 r/min motor is almost 50 percent larger than an 1800 r/min motor. At 600 r/min the motor is well over twice as large as the 1800 r/min motor. In the range from 1200 r/min to 900 r/min, the size and cost disadvantages may not be overwhelming factors. Where this is true, low-speed, directly coupled motors can be used. For example, this type of motor is used on most fans, pumps, and compressors.

PULLEY DRIVES

Installation

Flat belts, V-belts, chains, or gears are used on motors so that smooth speed changes at a constant r/min can be achieved. For speeds below 900 r/min, it is practical to use an 1800 r/min or 1200 r/min motor connected to the driven machine by a V-belt or a flat belt.

Machine shafts and bearings give long service when the power transmission devices are

properly installed according to the manufacturer's instructions.

Offset drives, such as V-belts, gears, and chain drives, can be lined up more easily than direct drives. Both the motor and load shafts must be level. A straightedge can be used to insure that the motor is aligned on its axis and that it is at the proper angular position so that the pulley sheaves of the motor and the load are in line, figure 52-4. When belts are installed, they should be tightened just enough to assure non-slip engagement. The less cross tension there is, the less wear there will be on the bearings involved. Proper and firm positioning and alignment are necessary to control the forces that cause vibration and the forces that cause thrust.

The designer of a driven machine usually determines the motor mount and the type of drive to be used. This means the installer has little choice in the motor location. In many flat belt or V-belt applications, however, the construction or maintenance electrician may be called upon to make several choices. If a choice can be made, the motor should be placed where the force of gravity helps to increase the grip of the belts. A vertical drive can cause problems because gravity tends to pull the belts away from the lower sheave, figure 52-5. To counteract this action, the belts require far more tension than the bearings should have to withstand. The elec-

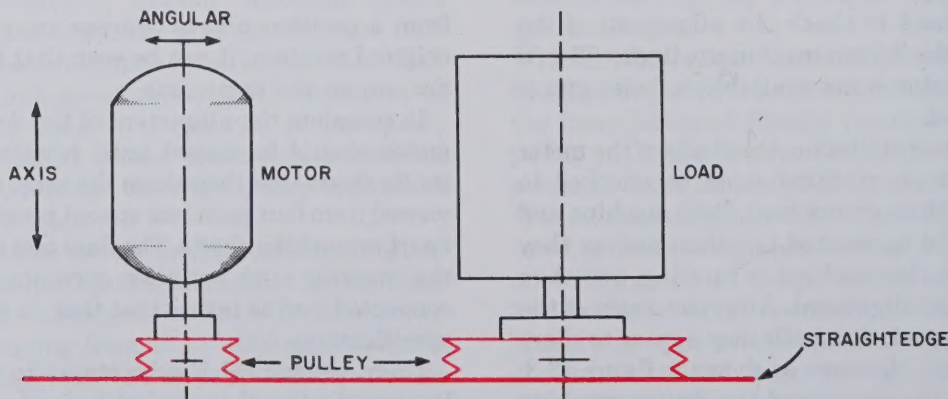


FIG. 52-4 Using straightedge for angular and axis alignment

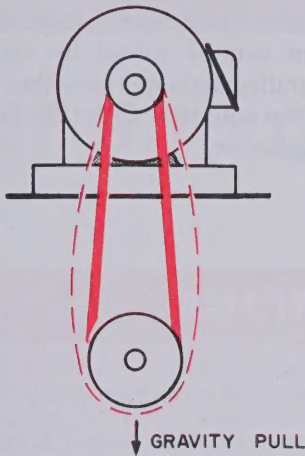


FIG. 52-5 Greater belt tension is required in vertical drives where gravity opposes good belt traction. This greater tension generally exceeds that which the bearings should withstand.

trician should avoid this type of installation, if possible.

There are correct and incorrect placements for horizontal drives. The location where the motor is to be installed can be determined from the direction of rotation of the motor shaft. It is recommended that the motor be placed with the direction of rotation so that the belt slack is on top. In this position, the belt tends to wrap around the sheaves. This problem is less acute

with V-belts than it is with flat belts or chains. Therefore, if rotation is to take place in both directions, V-belts should be used. In addition, the motor should be placed on the side of the most frequent direction of rotation, figure 52-6.

Pulley Speeds

Motors and machines are frequently shipped without pulleys or with pulleys of incorrect sizes. The drive and driven speeds are given on the motor and machine nameplates, or in the descriptive literature accompanying the machines.

Four quantities must be known if the machinery is to be set up with the correct pulley sizes: the drive revolutions per minute, the driven revolutions per minute, the diameter of the drive pulley, and the diameter of the driven pulley. If three of these quantities are known, the fourth quantity can be determined. For example, if a motor runs at 3600 r/min, the driven speed is 400 r/min, and there is a four-inch pulley for the motor, the size of the pulley for the driven load can be determined from the following equation.

$$\frac{\text{Drive r/min}}{\text{Driven r/min}} = \frac{\text{Driven Pulley Diameter}}{\text{Drive Pulley Diameter}}$$

$$\frac{3600}{400} = \frac{X}{4} \text{ or } \frac{3600}{400} = \frac{X}{4}$$

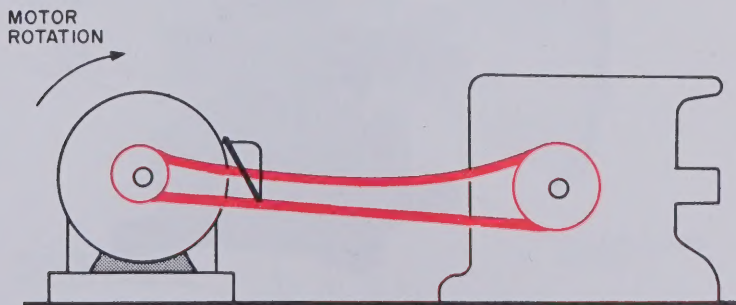


FIG. 52-6 Direction of motor rotation can be used to advantage for good belt traction (with slack at top) if motor is placed in proper position.

By cross multiplying and then dividing, we arrive at the pulley size required:

$$4X = 144$$

$$X = \frac{144}{4} = 36\text{-inch diameter pulley}$$

If both the drive and driven pulleys are missing, the problem can be solved by estimating a reasonable pulley diameter for either pulley and then using the equation with this value to find the fourth quantity.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What are the disadvantages of low-speed, directly coupled induction motors?
2. What type of ac motor can be directly coupled at low r/min with larger horsepower ratings?
3. What three alignment checks should be made to insure satisfactory and long service for directly coupled and belt-coupled power transmissions?
4. What special tools, not ordinarily carried by an electrician, are required to align a directly coupled, motor-generator set?
5. Induction motors should not be used below a certain speed (r/min). What is this speed?
6. What is the primary reason for using a pulley drive?
7. How tightly should V-belts be adjusted?
8. Refer to figure 52-6 and assume the motor is to rotate in the opposite direction. How can the belt slack be maintained on top?
9. A machine delivered for installation has a two-inch pulley on the motor and a six-inch pulley on the load. The motor nameplate reads 180 r/min. At what speed in r/min will the driven machine rotate?

UNIT 53 Gear Motors

Objectives After studying this unit, the student will be able to:

- Describe the basic operation of a gear motor
- State where gear motors are used generally
- Describe the three standard gear classifications
- Select the proper gears for the expected load characteristics

Many industrial machines require power at slow speeds and high torque. Conveyors and concrete mixers are typical examples of machinery with such requirements. At speeds of 780 r/min and less, the following drives may be prudently used: chain drive, belt drive, separate speed reducer coupled to the motor, or gear motor.

The gear motor is a speed-reducing motor that gives a direct power drive from a single unit. External gearing, figure 53-1 is not required, nor is the maintenance associated with such gearing. The gear motor provides an extremely compact, efficient, packaged power drive. A gear motor usually consists of a standard 1800 r/min ac or dc motor and a sealed gear train correctly

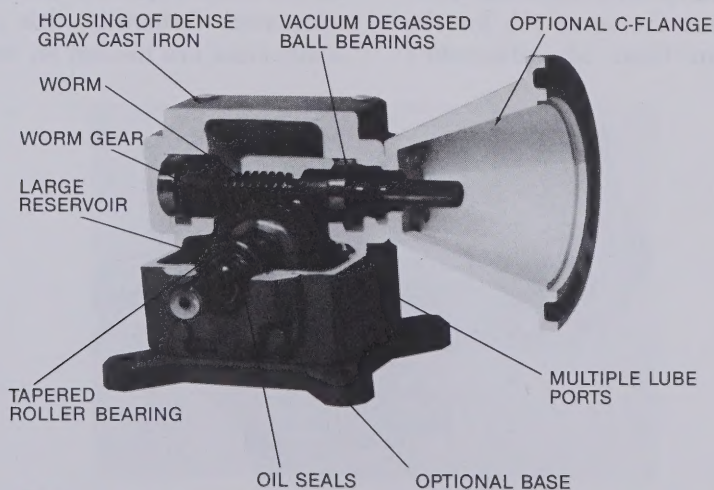


FIG. 53-1 One type of separate speed reducer: a right-angle gear drive

engineered for the load. This assembly is mounted on a single base as a one-package, enclosed power drive. The advantage of this unit is its extreme compactness. A gear motor actually is smaller than a low-speed standard motor of the same horsepower.

The motor-shaft pinion of the gear motor drives the gear or series of gears in an oil bath that is linked with the output shaft, figure 53-2. This type of arrangement is usually the most economical and convenient way to obtain low speeds of approximately *one* r/min to 780 r/min.

One-unit gear motors are available with the following options: (1) shafts parallel to each other or at right angles, (2) polyphase, single-phase, or direct-current voltages, and (3) horsepower ratings ranging from approximately 1/6 hp to 200 hp.

Gear motors are available in many of the standard motor types such as squirrel cage or wound rotor induction motors, running at either constant or adjustable speeds. The control equipment for the motor is selected the same as for any other motor of the same type.

When selecting a gear motor, an important consideration is the degree of gear service and gear life based on the load conditions to which the motor will be subjected. Gear motors are divided into three classes. Each class uses different gear sizes to handle specific load conditions. Each class gives about the same life for the gears. The American Gear Manufacturer's

Association has defined three operating conditions commonly found in industrial service and has established three standard gear classifications to meet these conditions:

- | | |
|-----------|--|
| Class I | For steady loads within the motor rating of 8 hours per day duration, or for intermittent operation under moderate shock conditions. |
| Class II | For 24-hour operation at steady loads within the motor rating, or 8-hour operation under moderate shock conditions. |
| Class III | For 24-hour operation under moderate shock conditions, or 8-hour operation under heavy shock conditions. |

For conditions that are more severe than those covered by Class III gears, a fluid drive unit may be incorporated in the assembly to cushion the shock to an acceptable value.

To achieve multiple speeds, separate units are available with a transmission comparable to that of an automobile. These units must be assembled with the motor and the driven machine. Since the amount of power lost in gearing is very small, the multiple drive has essentially constant horsepower. In other words, as the output speed is decreased, the torque is increased. Generally, this means that larger shaft sizes are needed for the output side.

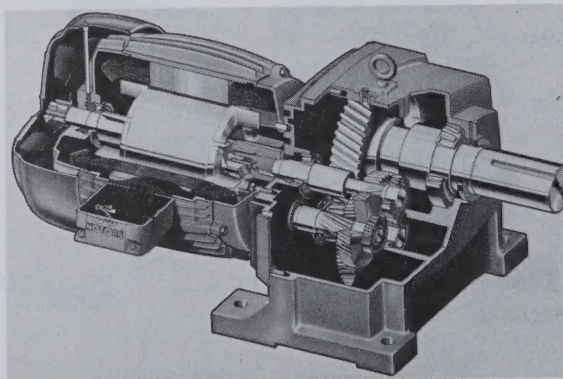


FIG. 53-2 Cutaway view of a speed reducing gear motor (double reduction)
(Courtesy U.S. Electrical Motors)

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Why do many industrial machines use gear motors instead of low r/min induction motors?
2. What is the principal difference in gear motor classifications?
3. In general, what is the maximum speed r/min of gear motors?
4. What is the classification of a gear motor that is subjected to continual reversing during an eight-hour production shift?
5. Why is the output shaft on a gear reduction motor larger than the shaft of a standard motor?

UNIT 54 Variable Frequency Mechanical Drives

Objectives After studying this unit, the student will be able to:

- Describe the operating principle of variable frequency drives
- State why variable frequency drives are used
- State the advantages of variable frequency drives

The speed of an ac squirrel cage induction motor depends upon the frequency of the supply current and the number of poles of the motor:

$$r/\text{min} = \frac{60 \times \text{Hertz}}{\text{Pairs of Poles}}$$

A frequency changer may be used to vary the speed of this type of motor.

Several methods can be used for one or more motors to obtain variable frequency from a fixed frequency power source. A common method is to drive an alternator through an adjustable mechanical speed drive. The voltage is regulated

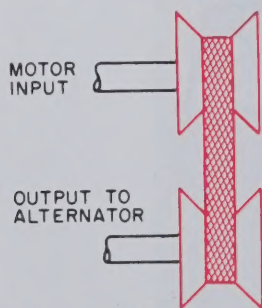


FIG. 54-1 Variable pitch pulleys; mechanical method of obtaining continuously adjustable speed from constant speed shaft

automatically during frequency changes. In this system, an ac motor drives a variable cone pulley, or sheave, which is belted to another variable pulley on the output shaft, figure 54-1. When the relative diameters of the two pulleys are changed, the speed between the input and the output can be controlled.

As the alternator speed is varied, the frequency varies. In cases where more than one motor is involved, such as in conveyor systems, all of the motors are connected electrically to the power system of the alternator. Each motor thus receives the same frequency and operates at the same speed. If a high-speed motor and a slow-speed gear motor are connected to the same variable frequency circuit, they will change speeds simultaneously and proportionally, figure 54-2. To obtain smooth acceleration of the motors attached to the alternator, the frequency is increased. Electric braking with suitable controls can be used in this system.

Variable frequency power drives are used on many different types of conveyor systems, figure 54-3. Assembly lines and coordinated screw conveyors for the proportional mixing of ingredients make use of these power drives, figure 54-2 and 54-4. Variable pitch systems are among

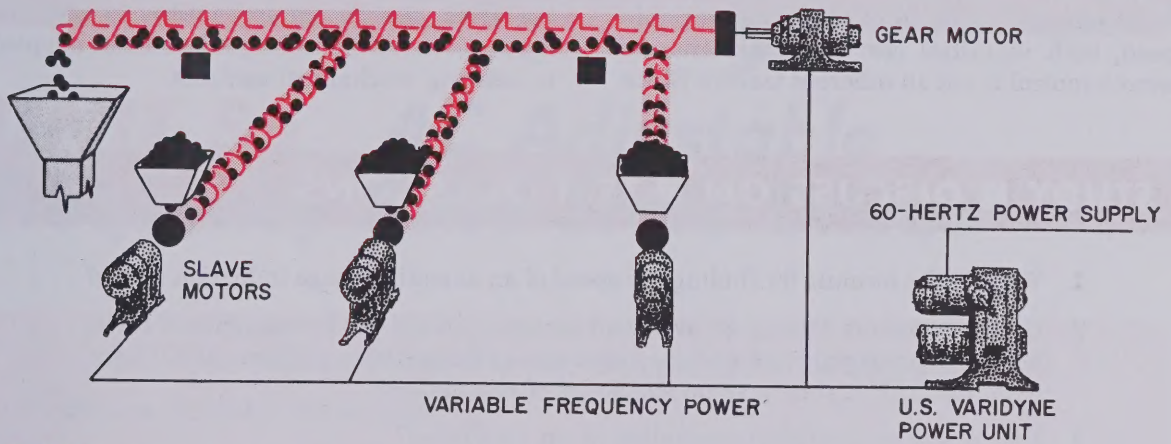


FIG. 54-2 Screw conveyors may be controlled individually by variable drive slave motors. Once the motors are set, they rotate at the same proportional r/min , controlled by the variable frequency power unit supplying them.

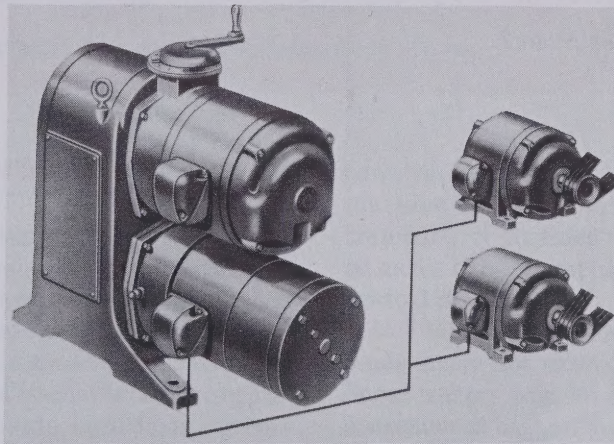


FIG. 54-3 Variable power unit used to control one or more motors at coordinated speeds (Courtesy U.S. Electrical Motors)

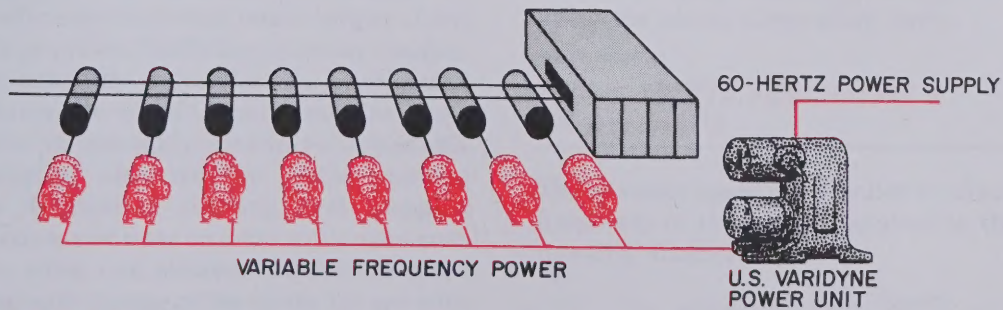


FIG. 54-4 Coordinating many drive motors, all of standard ac, squirrel cage construction

the lowest-cost methods of achieving variable speed, both in initial cost and maintenance. Remote control is not an inherent feature. Since

the drive uses mechanical means to vary the speed, electrical control signals must be adapted to existing mechanical controls.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What is the formula for finding the speed of an ac squirrel cage induction motor?
2. If several motors driving an overhead conveyor system are connected to a variable frequency supply line and the frequency is changed from 40 Hertz to 80 Hertz, what effect does this have on the speed of the motors?
3. How is the ac frequency controlled in an alternator?
4. If many feeder conveyor motors of different poles (speed) are connected to a main conveyor and to a variable frequency power unit, can increased production be achieved by increasing the frequency of the power unit? Explain your answer.
5. What is a *slave motor*?

UNIT 55 AC Adjustable Frequency Solid-State Drives

Objectives After studying this unit, the student will be able to:

- Discuss ac motor advantages
- Describe motor and load speed hazards
- Describe how the solid-state control changes frequency
- Describe the function of the converter and inverter
- Describe the features of adjustable frequency drives

AC MOTOR ADVANTAGES

Standard and energy-saving ac motors both are rugged and efficient. Their simple construction makes them highly dependable, even in the harshest industrial environments. They are also cost effective, require little maintenance, and are universally accepted and available. Teaming an ac motor with a reliable, precision drive controller gives the advantage of a system that is as efficient as it is dependable. Adding adjustable speed control to an ac motor enables the motor to provide significant advantages in energy efficiency and rated motor torque at any speed. It improves flexibility in many applications in assembly or production lines, using adjustable motor speed to match the line movement rate to assembly schedules. Adjustable speed control also reduces motor starting stresses. Controlled starting and stopping reduces stress and wear on drive equipment such as gears, belts, and sheaves. Adjustable speed allows variable torque of the motor for use with fans and pumps, constant torque for use with

conveyors, or constant horsepower for use with machine tools. By changing the frequency electronically, it provides versatility by allowing an ac motor to be operated beyond its normal rating, up to 120 hertz.

CAUTION: Ac motors and their connected loads must not exceed safe operating speeds. Some motors and loads may not be suited for operation at higher-than-nameplate speeds and frequencies. To avoid destruction of the motor and driven load, plus potential injury to people from possible destructive overspeed, consult the motor and equipment manufacturer before operating the motor above sixty hertz.

SOLID-STATE FREQUENCY CHANGING

The ac motor speed is controlled by changing the frequency of the voltage applied to the stator rotating magnetic field.

$$\text{R/min} = \frac{60 \times \text{Hertz}}{\text{Pairs of poles}}$$

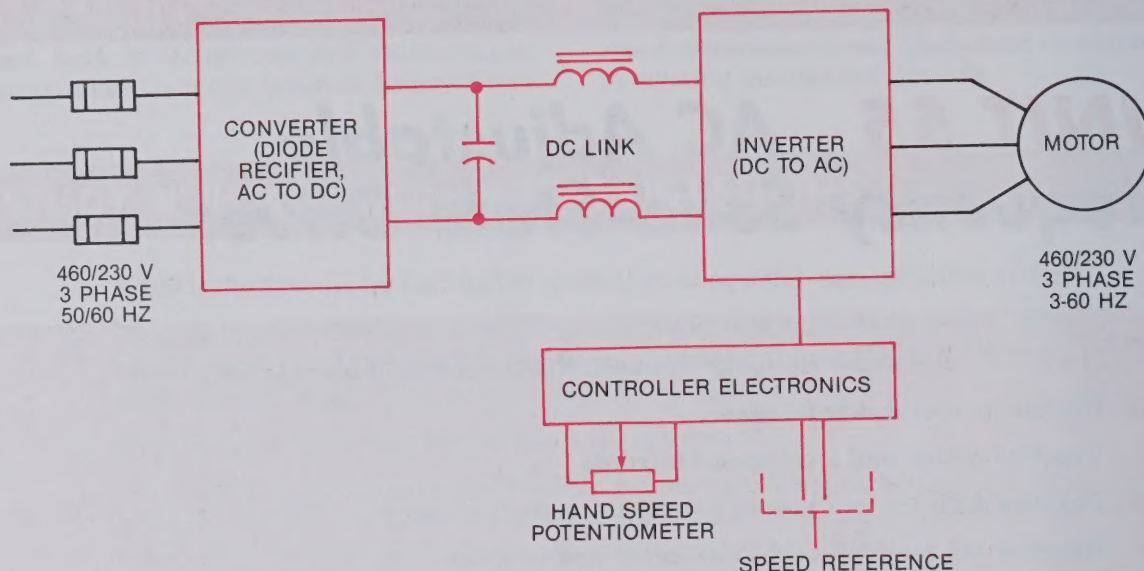


FIG. 55-1 Block diagram of an ac adjustable speed drive

The frequency change in the stator rotating magnetic field changes in proportion to the speed of the motor rotor. Adjusting the speed is accomplished by converting the fixed incoming ac line voltage to an adjustable frequency source. A common adjustable frequency control converts ac line voltage to adjustable dc, and then inverts the dc to adjustable frequency ac, figure 55-1.

Converter (Rectifier)

The function of the converter is to change the ac input line voltage to a fixed dc voltage. This rectifier stage consists of six power diodes arranged in a three-phase, full-wave bridge configuration. The purpose of the rectifier is to change fixed voltage, fixed frequency ac voltage to dc voltage. It is not necessary to control the rectifier diodes here; thus the diode bridge rectifier is used.

DC Link

The dc link couples the rectifier output to the inverter input. The dc link includes capacitors to filter the ripple present on the rectified output

voltage to a smooth dc voltage. The circuit inductors help protect the inverter power switching devices from short circuits or ground faults. They do this by limiting the rate at which dc current can change in magnitude.

Inverter

The inverter section changes dc voltage to three-phase ac voltage at the selected frequency. It consists of six Gate Turn Off (GTO) thyristors which reconstruct a three-phase ac waveform for application to a standard three-phase ac motor. A switching technique is used which provides a simulation of ac sine waves, figure 55-2.

FEATURES

The ac drive has many of the features possessed by the dc drive, such as modular components (power transistors, driver circuits, main logic board, power supply and rectifier assembly) for easier service. These components are similar to the modules shown in figure 55-3. LED (light emitting diode) controller and motor status indi-

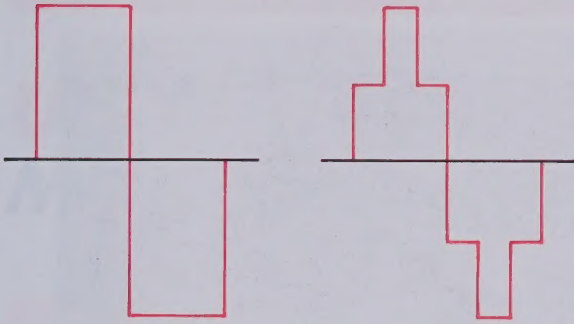


FIG. 55-2 Different adjustable output "waveforms." While these synthesized waveforms are not an ideal sine-wave shape they are satisfactory for motor operation, with an acceptable increase in motor heating (losses). This is considered in motor selection.

cators are located on each board or module. They monitor critical signals and indicate operational status.

Some drives have finned, totally enclosed construction. This allows installation in most industrial atmospheres without requiring air-conditioned or special environmental rooms. Cooling is achieved through convection and radiation, eliminating fans and filters, figure 55-4.

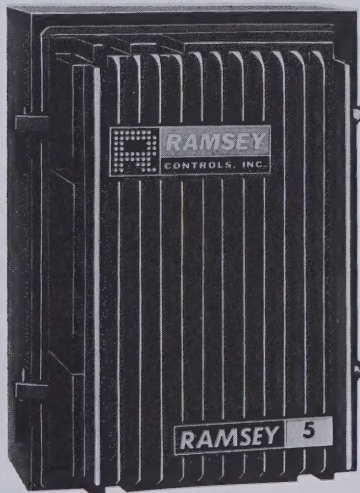


FIG. 55-4 The fins on this drive enclosure permit cooling by convection and radiation, thus eliminating fans and filters (Courtesy of Square D Co.)

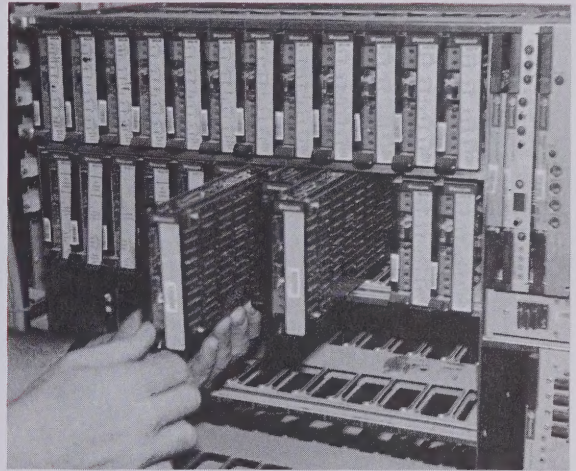


FIG. 55-3 Changing electronic modules

Extremely high ambient temperatures sometimes cause flashovers and shoot-throughs of power SCRs.

Controllers are available with hand/automatic, reversing and jogging controls, dynamic braking, and all the protective features of electromagnetic controllers. A control station is shown in figure 55-5. An adjustable frequency controller is shown in figure 55-6.

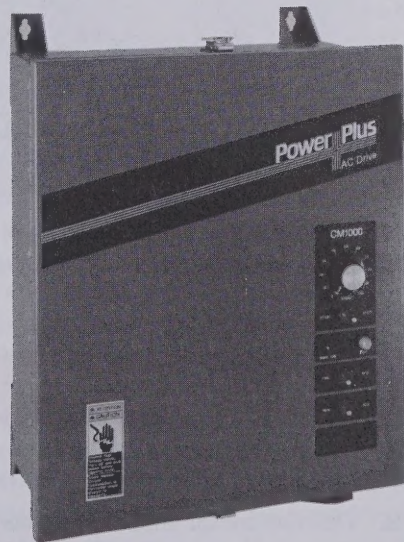


FIG. 55-5 A typical ac drive control station (Courtesy of Warner Electric)

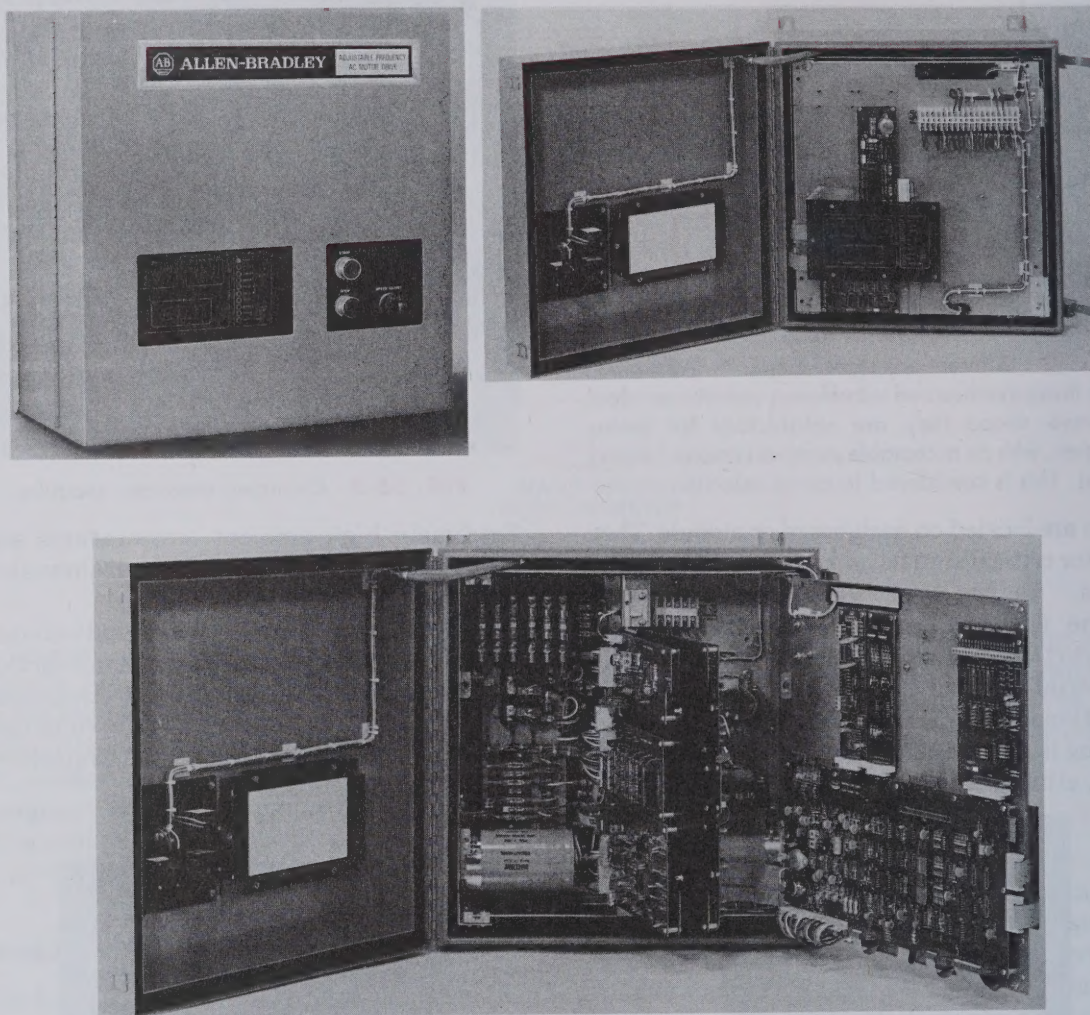


FIG. 55-6 Adjustable frequency motor drive controller (Courtesy of Allen-Bradley Company, Drives Division)

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What are some ac motor drive advantages?
2. Discuss motor and load speed hazards.
3. Briefly describe the power processes in changing motor speeds.
4. Describe some features of the ac drive.

UNIT 56 *Magnetic Clutch and Magnetic Drive*

Objectives After studying this unit, the student will be able to:

- State several advantages of the use of a clutch in a drive
- Describe the operating principles of magnetic clutches and drives
- Distinguish between single and multiple-face clutches
- Connect magnetic clutch and magnetic drive controls
- Recommend troubleshooting solutions for magnetic clutch and drive problems

ELECTRICALLY CONTROLLED MAGNETIC CLUTCHES

Machinery clutches were originally designed to engage very large motors to their loads after the motors had reached running speeds, figure 56-1. Clutches provide smooth starts for operations in which the material being processed might be damaged by abrupt starts, figure 56-2. Clutches are also used to start high-inertia loads, since the starting may be difficult for a motor that is sized to handle the running load. When starting conditions are severe, a clutch inserted between the motor and the load means that the motor can run within its load capacity. The motor will take longer to bring the load up to speed, but the motor and load will not be damaged.

As more automatic cycling and faster cycling rates are being required in industrial production, electrically controlled clutches are being used more often.

Single-face Clutch

The single-face clutch consists of two discs: one is the field member (electromagnet) and the other is the armature member. The operation of the clutch is similar to that of the electromagnet in a motor starter, figure 56-3. The principle of operation is shown in figure 56-3. However, this is done more frequently electronically using solid-state devices. SCRs are gated to regulate the current flow as in (A) and to switch power as in (B). When current is applied to the field winding disc through collector (slip) rings, the two discs are drawn together magnetically. The friction face of the field disc is held tightly against the armature disc to provide positive engagement between the rotating drives. When the current is removed, a spring action separates the faces to provide a definite clearance between the discs. In this manner, the motor is mechanically disconnected from the load.

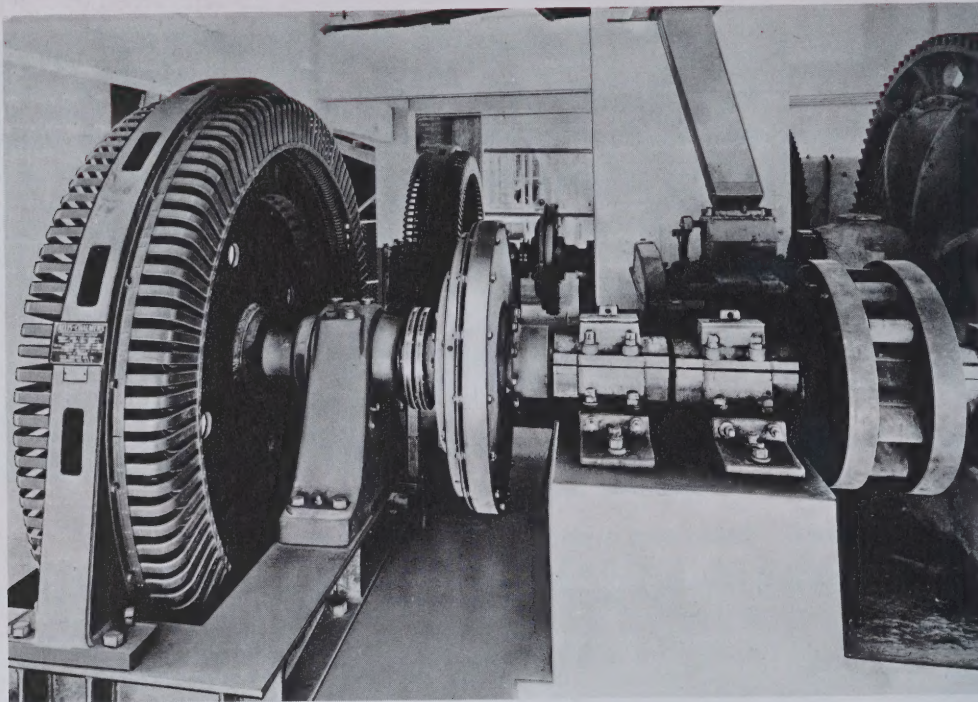


FIG. 56-1 Magnetic clutches in cement mill service. Note slip rings for clutch supply.

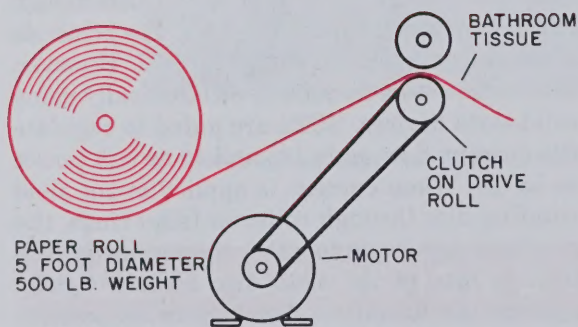


FIG. 56-2 To prevent tearing, a cushioned start is required on drive roll that winds bathroom tissue off large roll. Roll is five feet in diameter and weighs 500 pounds when full. Pickup of thin tissue must be very gradual to avoid tearing. Application also can be used for filmstrip processing machine.

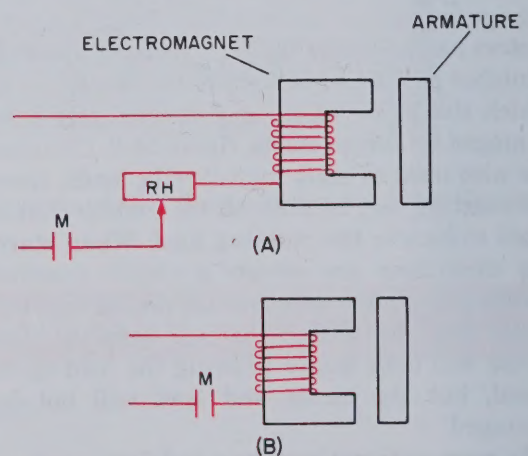


FIG. 56-3 Principle of operation of electrically controlled clutches: (A) gradual clutch engagement; (B) more rapid clutch engagement

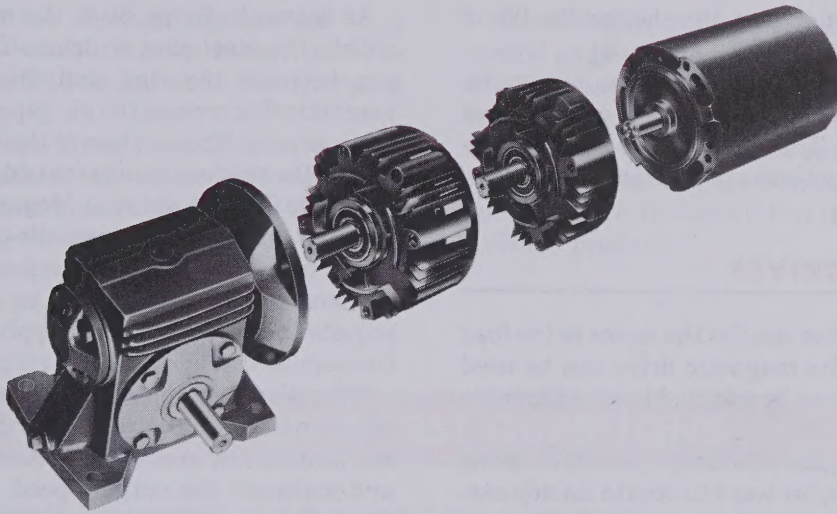


FIG. 56-4 Electric brake and electric clutch modules. Brake is shown on the center left on the driven machine side of the clutch. (Courtesy Warner Electric Brake and Clutch Co.)

Multiple-face Clutch

Multiple-face clutches are also available. In a double-face clutch, both the armature and field discs are mounted on a single hub with a double-faced friction lining supported between them. When the magnet of the field member is energized, the armature and field members are drawn together. They grip the lining between them to provide the driving torque. When the magnet is de-energized, a spring separates the two members and they rotate independently of each other. Double-face clutches are available in sizes up to 78 inches in diameter.

A water-cooled magnetic clutch is available for applications which require a high degree of slippage between the input and output rotating members. Uses for this type of clutch include tension control (wind-up and payoff) and cycling (starting and stopping) operations in which large differences between the input and the output speeds are required. Flowing water removes the heat generated by the continued slippage within the clutch. A rotary water union mounted in the end of the rotor shaft means that the water-cooled clutch can not be end-coupled directly to the prime mover. Chains or gears must be used.

A combination clutch and magnetic brake disconnects the load from the drive and simultaneously applies a brake to the load side of the drive. Magnetic clutches and brakes are often used as mechanical power-switching devices in module form. Figure 56-4 shows a drive line with an electric clutch (center right) and an electric brake. An application of this arrangement is shown in figure 56-5. Remember that the

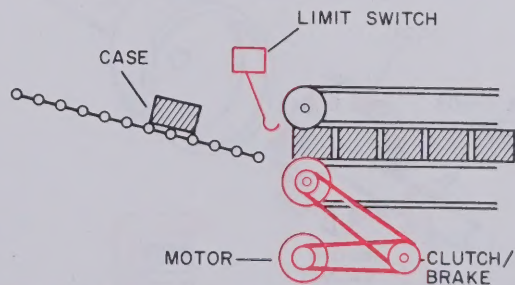


FIG. 56-5 Case sealer is used to hold top of carton while glue is drying. In the application, cartons come down gravity conveyor and hit switch in front of sealer. Clutch on sealer drive is engaged, moving all cartons in sealer forward. When new carton passes trip switch, brake is engaged and clutch disengaged. Positioning provides even spacing of cartons, insuring that they are in the sealer for as long a time as possible.

quicker the start or stop, the shorter the life of this equipment.

Magnetic clutches are used on automatic machines for starting, running, cycling, and torque-limiting. The combinations and variations of these functions are practically limitless.

MAGNETIC DRIVES

The magnetic drive couples the motor to the load magnetically. The magnetic drive can be used as a clutch and can be adapted to an adjustable speed drive.

The electromagnetic (or eddy current) coupling is one of the simpler ways to obtain an adjustable output speed from the constant input speed of squirrel cage motors.

There is no mechanical contact between the rotating members of the magnetic drive. Thus, there is no wear. Torque is transmitted between the two rotating units by an electromagnetic reaction created by an energized coil winding. The slip between the motor and load can be controlled continuously, with more precision, and over a wider range than is possible with the mechanical friction clutch.

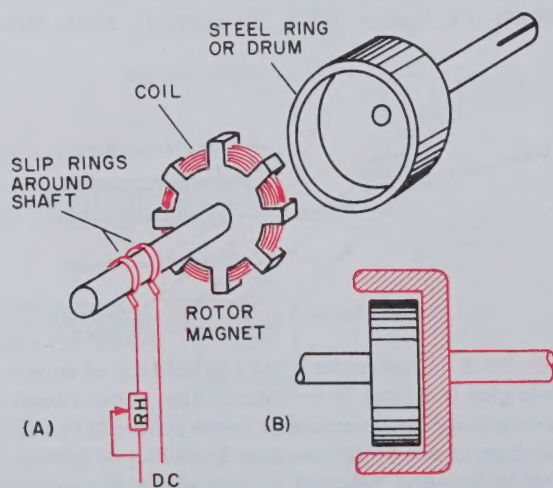


FIG. 56-6 Diagram showing (A) open view of magnetic drive assembly; (B) spider rotor magnet rotates within ring.

As shown in figure 56-6, the magnet rotates within the steel ring or drum. There is an air gap between the ring and the magnet. The magnetic flux crosses the air gap and penetrates the iron ring. The rotation of the ring with relation to the magnet generates eddy currents and magnetic fields in the ring. Magnetic interaction between the two units transmits torque from the motor to the load. This torque is controlled with a rheostat which manually or automatically adjusts the direct current supplied to the electromagnet through the slip rings.

When the electromagnetic drive responds to an input or command voltage, a further refinement can be obtained in automatic control to regulate and maintain the output speed. The magnetic drive can be used with any type of actuating device or transducer that can provide an electrical signal. For example, electronic controls and sensors which detect liquid level, air and fluid pressure, temperature, and frequency can provide the input required.

A tachometer generator provides feedback speed control in that it generates a voltage that is proportional to its speed. Any changes in load condition will change the speed. The resulting

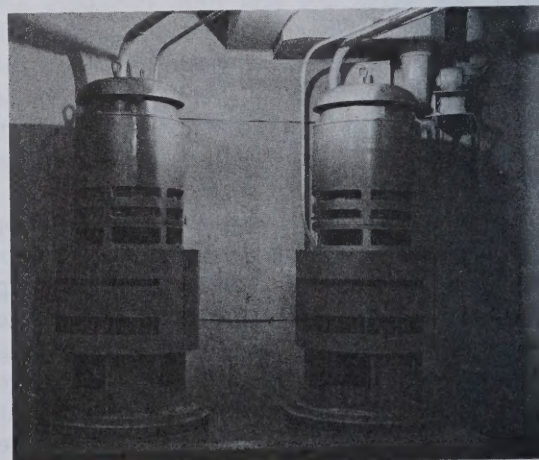


FIG. 56-7 Two magnetic drives driven by 100-hp, 1200-rpm induction motors mounted on top. Machines are used in typical sewage pumping plant. Pumps are mounted beneath floor of drives. (Courtesy Electric Machinery Mfg. Co.)

generator voltage fluctuations are fed to a control circuit which increases or decreases the magnetic drive field excitation to hold the speed constant.

For applications where a magnetic drive meets the requirements, an adjustable speed is frequently a desirable choice. Magnetic drives are used for applications requiring an adjustable speed such as cranes, hoists, fans, compressors, and pumps, figure 56-7.

An electronic microprocessor unit is used to control and regulate the tension applied to strips of metal, paper, film, wire, and cable during the course of processing. It controls the speed and diameter fluctuations of the spool coils. Further, it ensures a constant tension, even at high linear speeds, which is essential to the quality of the finished product.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. How is the magnetic clutch engaged and disengaged?
2. What devices may be used to energize the magnetic clutch?
3. Which type of drive is best suited for maintaining large differences in the input and output speeds? Why?
4. What is meant by feedback speed control?
5. How is the magnetic drive used as an adjustable speed drive?

UNIT 57 *DC Variable Speed Control — Motor Drives*

Objectives After studying this unit, the student will be able to:

- Describe the operating principles of dc variable speed control motor drives
- State how above and below dc motor base speeds may be obtained
- List three advantages of dc variable speed motor drives
- List modifications which can be made to packaged variable speed control drives to meet specific applications
- Connect dc variable speed control motor drives
- Recommend troubleshooting solutions

Adjustable speed drives are available in convenient units that include all necessary control circuits, figure 57-1. These packaged variable speed drives generally operate on ac. They provide a large choice of speeds within given ranges.

Some drive requirements are so exacting that the ac motor drive alone is not suitable. In such cases, the dc motor has characteristics not available with ac motors. The dc motor also possesses many of the characteristics of an ac motor. A dc shunt motor with adjustable voltage control is very versatile and can be adapted to a large variety of applications.

The ac service in industrial plants must be converted to dc for use with these controls. Smooth and easily controlled dc is obtained through the use of the Ward Leonard system in which a dc shunt generator with field control is driven by an induction motor.

As described in previous units, electricity can be generated electromagnetically for heavy

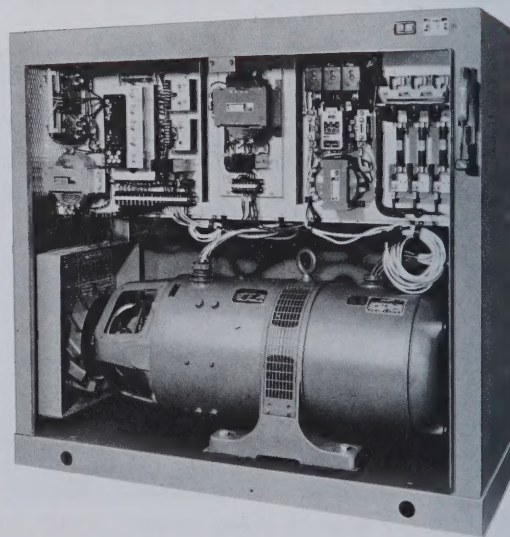


FIG. 57-1 Packaged-type motor-generator with dc variable speed control system supplied from ac (Courtesy Square D Co.)

power consumption only if the following are present:

- A magnetic field
- A conductor
- Relative motion between the two

The motion in the dc variable speed drive of figure 57-2 is maintained by the steady driving force of an induction motor. The generator voltage is increased by increasing the magnetic flux in the generator field. The magnetic flux of the generator field is increased by decreasing the resistance of the field rheostat to allow more current to flow through the shunt winding. Thus, the greater the field current, the stronger is the magnetic field.

The speed and torque of the system shown in figure 57-2 can be controlled by adjusting the voltage to the field or to the armature or both. Speeds above the motor base (nameplate) speed are obtained by weakening the motor shunt field with a rheostat or electronically. Speeds below the motor base speed are obtained by weakening the generator field. This, in turn, lowers the generator voltage supplying the dc motor armature. The motor should have a full shunt field for speeds lower than the base speed to give the effect of almost continuous control, rather than step control of the motor speed.

The motor used to furnish power from the line may be a three-phase induction motor, as shown in figure 57-2, or it may be a dc motor. Once the

driving motor is started, it runs continuously at a constant speed to drive the dc generator.

The armature of the generator is coupled electrically to the motor armature as shown. If the field strength of the generator is varied, the voltage from the dc generator can be controlled to send any amount of current to the dc motor. As a result, the motor can be made to turn at many different speeds. Because of the inductance of the dc fields and the time required by the generator to build up voltage, extremely smooth acceleration or deceleration is obtained from zero R/min to speeds greater than the base speed.

The field of the dc generator can be reversed manually or automatically with a resulting reversal of the motor rotation.

The generator field resistance can be changed manually or automatically by the time-delay relays operated by a counter emf across the motor armature.

Electrically controlled variable speed drives offer a wide choice of speed ranges, horsepower and torque characteristics, means for controlling acceleration and deceleration, and methods of manual or automatic operation. A controlling tachometer feedback signal may be driven by the dc motor driveshaft. This is a refinement of the system to obtain constant speed. The choice of this method depends on the type of application, the speed, and the degree of response required (similar to the magnetic drive automatic control). In addition to speed, the controlling

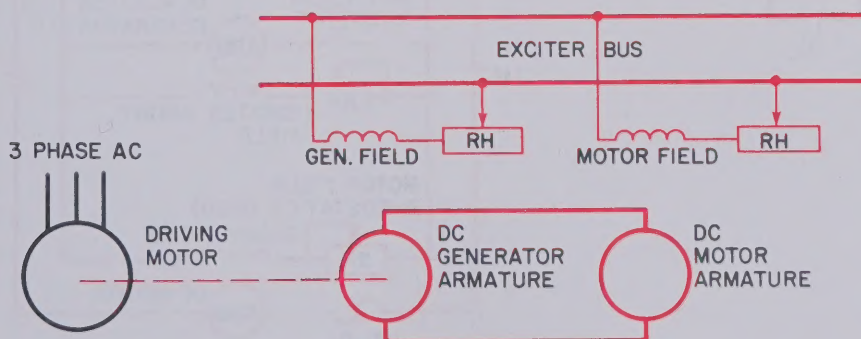


FIG. 57-2 Basic electrical circuit of a dc variable speed control system

feedback signal may be set to respond to pressure, tension, or some other transducer function.

The circuit used with a motor-generator set to obtain adjustable voltage is shown in figure 57-3. In this circuit, the exciter has closed connections. An ac motor, usually a squirrel cage motor, drives the dc generator and exciter. The exciter may be operated as a self-excited machine and set to give constant potential output.

The generator field is connected directly across the constant potential exciter. The motor field may be weakened to provide speeds above the base speed after the generator voltage is increased to its maximum value.

The motor-generator set has one inherent advantage over rectifier-type dc supplies; that is, the ability to regenerate.

In figure 57-3, assume that the generator rheostat is set at its maximum point and the motor is running at base speed. If the generator voltage is decreased by adjusting the rheostat, the motor countervoltage will be higher than the generator voltage and the current reverses. This action results in a reverse torque in the machine and the motor slows down (dynamic braking). This dynamic braking feature is very desirable when used on metal working, textile and paper processing machines, and for general industry use.

MODIFICATIONS

To meet specific operating requirements, the packaged variable speed control drives can be

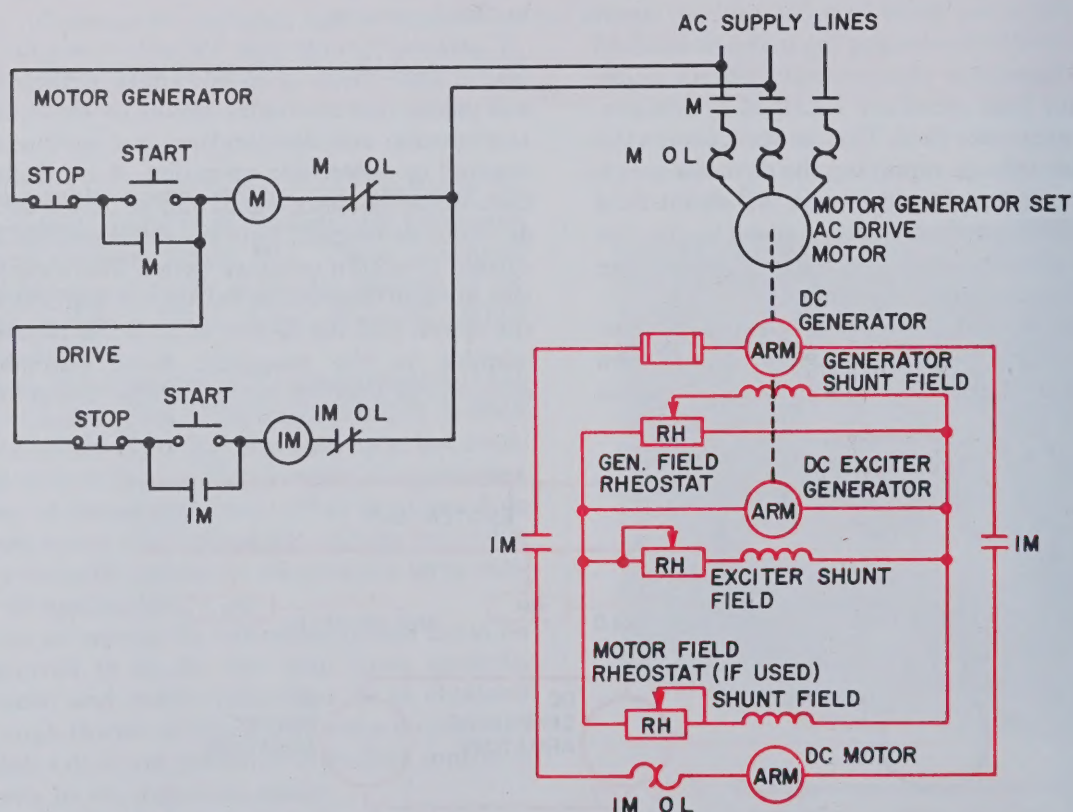


FIG. 57-3 Electrical power and control connections for dc variable speed control system

furnished with a variety of modifications, including provisions for:

- Multimotor drive
- Reversing by reversing the generator field
- Reversing by motor armature control
- Dynamic and regenerative braking
- Motor-operated rheostat operation
- Preset speed control
- Jogging at preset reduced speed
- Current or voltage (speed) regulation
- Timed rate of acceleration and deceleration
- Current-limit acceleration and deceleration

The generator field resistance can be changed manually or automatically by time relays operated by a counter emf across the motor armature. Motor-operated rheostats can also be used in automatic speed control operations.

One or more of these modifications can be combined as required by the specific application. Some control schemes eliminate the standard exciter and provide other methods of energizing the generator and motor fields. Some systems eliminate the motor-generator set entirely and supply the armature and field power through controlled rectifiers directly to the motor from ac lines.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. What is meant by the base speed of a dc motor?
2. How is above base speed obtained?
3. How is sub-base speed for a dc motor obtained?
4. What advantage does the motor-generator type of variable speed drive have over rectifier-type dc supplies?
5. If the ac driving motor of a self-excited motor-generator set is reversed, does this reverse the direction of rotation of the dc motor? Explain.
6. How does reversing the generator polarity reverse the connected motor or motors?
7. Why should the motor have a full shunt field for below-base speed operation?
8. To increase generator voltage: (a) should the resistance of the rheostat be increased or decreased; (b) what change in current condition is required in the shunt field? Why?

UNIT 58 Programmable and Motion Control

Objectives After studying this unit, the student will be able to:

- Discuss the operation of the input/output modules, the central processing unit, and the operator programming terminal
- Draw basic diagrams of how the input and output modules function
- Convert a motor starter elementary drawing to a schematic used for programming a programmable controller
- Connect some pilot and control devices to input/output modules
- Discuss installation requirements for a programmable controller
- Discuss the use of PC programmer circuit on and off display
- Describe some different motors used in automated systems
- Describe a modern motor control center

PROGRAMMABLE CONTROLLERS

If you set your alarm clock or clock radio to wake your household in the morning, you have programmed a controller. Programmable controllers range in size from small, versatile controllers that run single machines, to large, complex controllers that oversee entire control networks.

A programmable controller is a solid-state, electronic microprocessor-based control system used widely in industry. The system monitors input signals to detect changes from connected sources such as push buttons, limit switches, and condition sensors. Based upon the status of input signals, the controller system reacts by means of user-programmed internal logic. The reaction

is to produce output signals to drive external loads such as control relays, motor starters, contactors, and alarms or annunciators, figure 58-1. Because of their flexibility, accuracy, and economy, more control needs are being met by programmable controllers (PCs) in industry. PCs are available in all sizes. Small ones are equal to as few as five relays, figure 58-2. The controller shown in figure 58-2 is specifically designed for use in automated process control and/or machine control. Large units are equal to thousands of inputs and outputs. This type of control system is widely used in batch processing and special machine control applications. By simply changing an “elementary ladder diagram” stored in the microcomputer logic, program changes are made, thereby changing

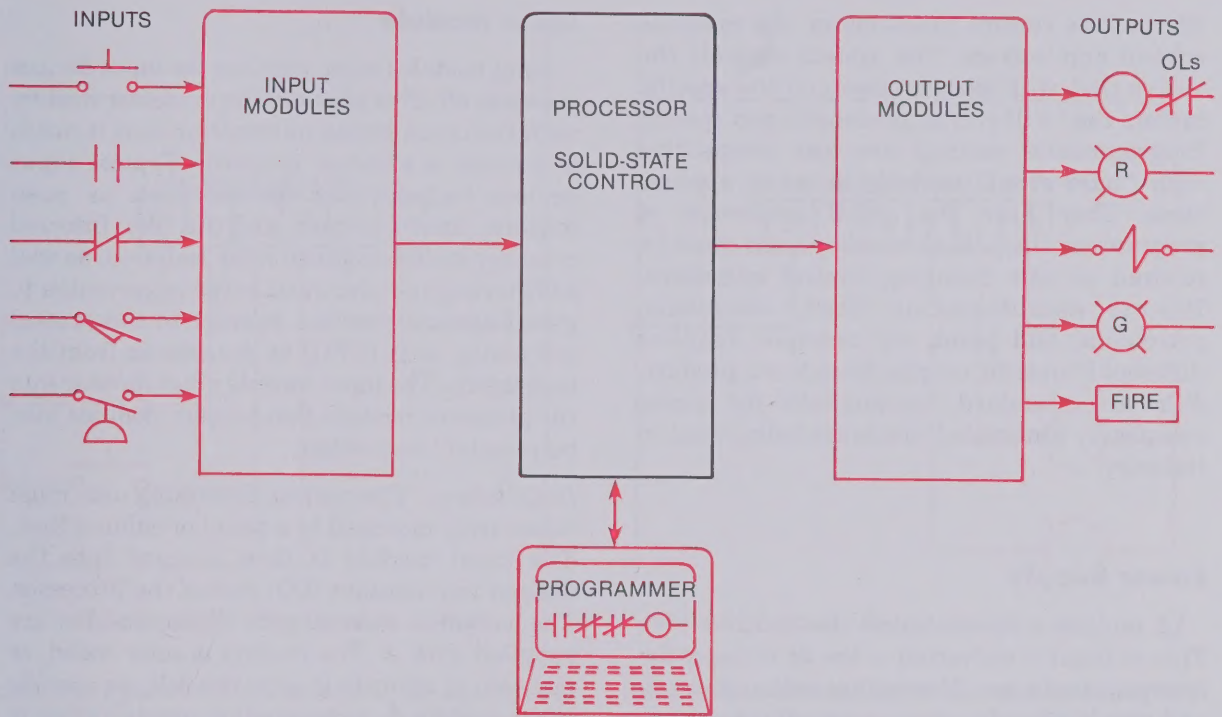


FIG. 58-1 Based upon input signals and the program entered into the processor, the output is controlled.

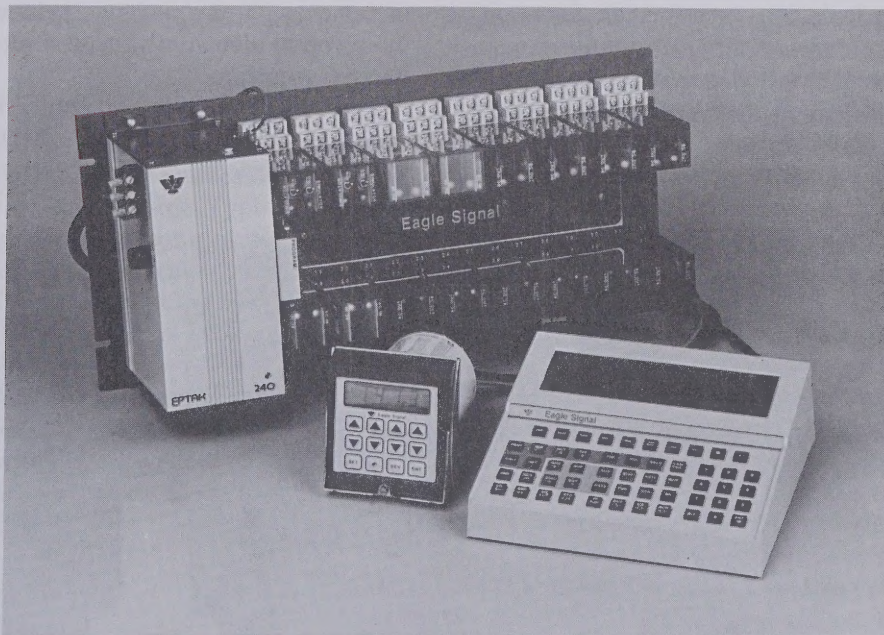


FIG. 58-2 Small programmable controller with input/output track, designed for use in automatic process control (Courtesy of Eagle Signal Controls)

the process control functions or the machine control applications. The system controls the valves that will open or close and the specific motors that will run at predetermined speeds. Programmable controls are cost competitive with “hard-wired” controls in many applications. They have the added advantage of programmability. Hard-wired systems must be rewired to suit changing control situations. Process manufacturing (food, chemicals, petroleum, and paint, for example) requires different blends for varying brands of a product. PCs are standard components for many completely automated machines being used in industry.

Power Supply

L1 and L2 still mean line one and line two. This ac input is converted to low dc voltages for internal circuit use. The voltage is then filtered and regulated to free the system of any electrical spikes and noise. It might still be necessary to install an isolating transformer. Some PC manufacturers may recommend installing noise suppressors on all magnetic switches being used with their system. Always pay close attention to the manufacturer’s installation instructions and recommended operating procedures.

Input Module

Input modules sense whether the input devices are on or off. This provides the processor module with the input status information that it needs to process a planned program. Typical input devices include pilot devices such as push buttons, limit switches, and the like. Internal circuitry includes optical relay isolation, as well as filtering and electrical surge suppression to guard against possible damage to the central processing unit (CPU) by transients from the user inputs. The input module plugs directly into the processor module. Some input modules may be remotely connected.

Installation. The central processing unit must be securely mounted to a panel or cabinet first. The input module is then plugged into the desired input/output (I/O) port of the processor. The module is secured with the screws that are supplied with it. The module is color coded, or marked, to identify it as a 120-volt, ac specific input module. A corresponding identification is placed on the processor module. If the module is removed for any reason, this identification will help you to identify the type of module assigned to this location.

Figure 58-3A shows an input module on the right connected to a control unit (CPU). A typical electrical ladder connection diagram is

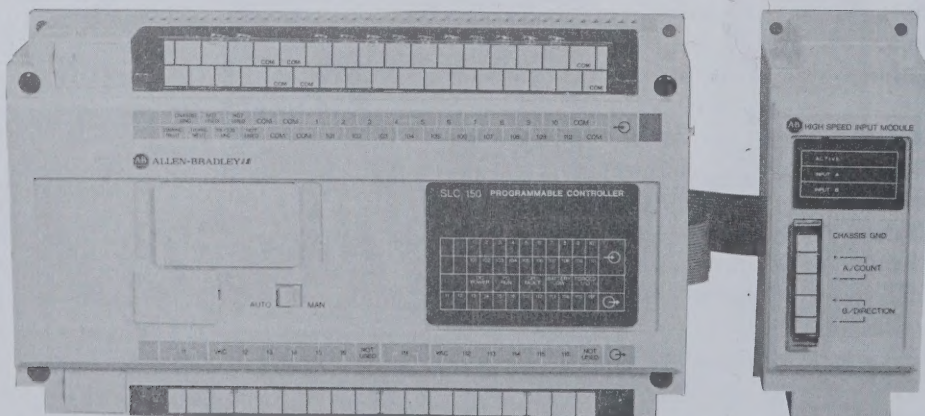


FIG. 58-3(A) Input module wiring

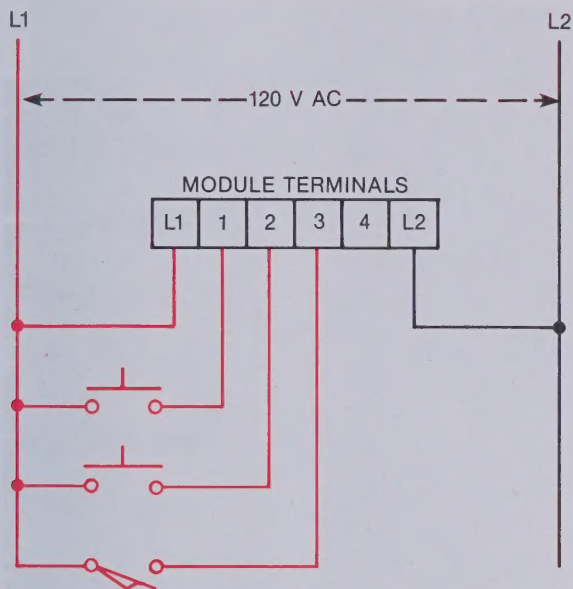


FIG. 58-3(B) Input module wiring

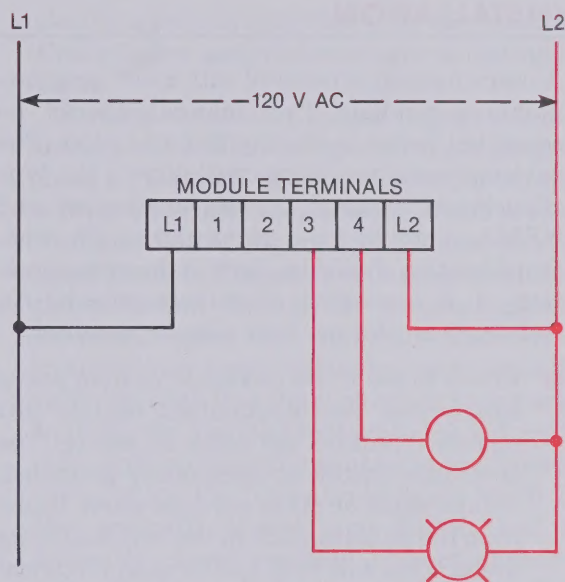


FIG. 58-4 Output module wiring

shown in figure 58-3B. The wiring for the external push buttons must be brought to the PC cabinet in conduit or to comply with the National Electrical Code requirements.

Output Module

Output modules control ON and OFF status of output devices, based on commands received from the processor control unit. Typical output devices include coils for motor starters, contactors, relays, etc. Some output modules are capable of switching starters through size five. Module protective circuitry is built in like the input module. It also plugs directly into the processor unit. Status indicator lamps are available, as with the input module. A typical terminal elementary diagram is shown in figure 58-4. The physical appearance is similar to that of the input module.

Processor Unit

The processor unit is the principal unit of the controller. It processes and manipulates the

information entered in its memory by the operator terminal or programmer. Working with or interfacing with external hard-wired input and output devices is accomplished using the input and output modules. These are plugged into the I/O (input/output) ports of the processor module.

The number of input/outputs, and the capacity to handle them, determines the size of the programmable controller. Even the small processors are a maze of electronic printed circuits, transistors, and other related equipment. Both digital (on/off) and analog signals (such as voltage and current values) are acceptable to the processor. These signals are handled differently internally, but can be connected within limits.

The brain of the programmable controller is the processor. It receives all inputs, evaluates and organizes the control activity, and performs logical decisions according to the direction of the memory stored program. It then tells the output what to do. The processor module supplies operating power to the input and output modules and the operator terminal (programmer). Input and output devices must be separately powered, as may be seen in figures 58-3 and 58-4.

INSTALLATION

A user's manual is received with a new programmable controller. This manual should be consulted before installing the controller. The environmental conditions will dictate the type of enclosure required. It must be adequate and NEMA approved for a particular application. Consideration should be given to the proper location of a controller disconnect switch. An isolation transformer may also be required.

- Check to see if the processor module power supply and the input/output devices (I/O modules) require the same ac source. The controller should be adequately grounded. Scrape paint or other nonconductive finish from the panel surface in the bolt mounting areas. This will help assure good electrical contact for grounding purposes, when the mounting bolts are tightened.
- Check to see if one or more emergency stop switches are to be included, or recommended. The location of such switches is also an important consideration.
- Follow the manufacturer's recommendations for component or accessory spacing within the enclosure. This is to help keep the controller temperature within safe operating limits.
- Check to see how the wiring should be routed to minimize the effects of electrical noise.
- Are surge suppressors to be used for inductive loads in series with hard contacts and for other noise-generating equipment?
- Where many machines or processes are controlled by one processor, it may be economically advantageous to locate I/O modules close to the field devices. This reduces multiple conductor runs. It also locates the I/O module indicator lights close to the machine or process for easy field monitoring and troubleshooting.

Figure 58-5 shows an I/O track that is wired. The module is plugged into a wired track as can be seen at the upper right. No field wiring need

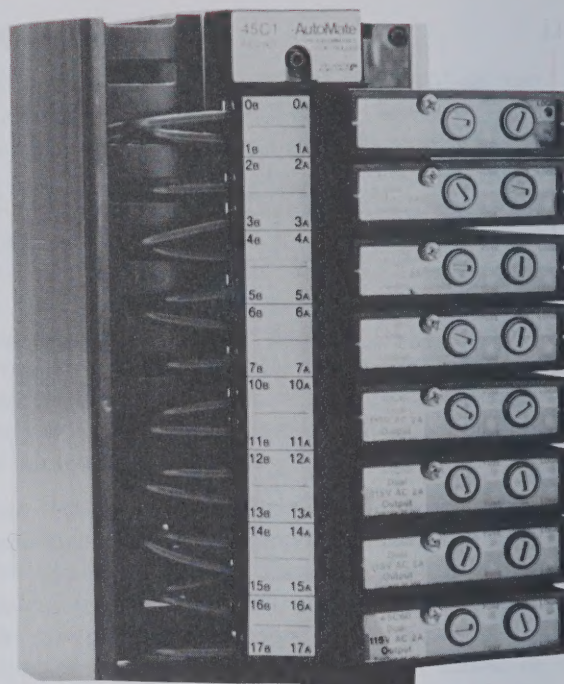


FIG. 58-5 A wired I/O module (Courtesy of Reliance Electric)

be removed during maintenance or changing modules in this scheme. In checking the user's manual for these few recommendations, other installation suggestions or requirements should be noted before installation.

PROGRAMMER TERMINAL

The programming unit, or operator terminal, permits information to be input to the processor through a keyboard. This input information tells the processor what to do with control loads connected to the output modules. This information includes the step-by-step circuit layout and connections. Figure 58-6 shows a hand-held programmer terminal plugged into the processor at the left.

Programming may be accomplished either at the processor site or remote to the processor, as in figure 58-6. Stationary program terminal

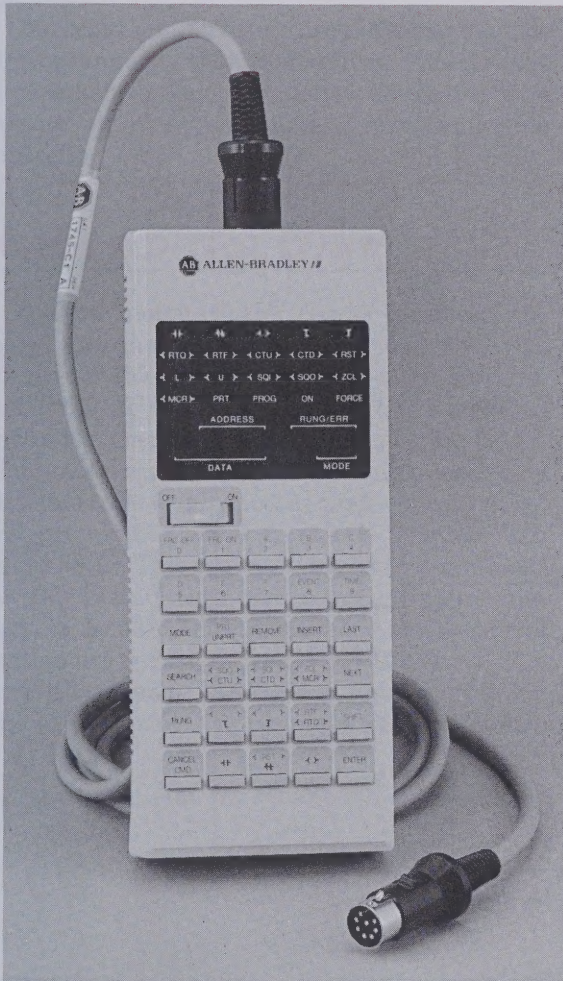


FIG. 58-6 Entering control logic into the processor from an operator program terminal (Courtesy of Allen-Bradley Co.)

keyboards may be much larger and wired and attached to a video monitor, looking like a television set with a typewriter keyboard. The more familiar relay ladder diagram format is commonly used to program this processor.

Elementary, ladder diagramming ability is essential.

All pilot devices are programmed as normally open or normally closed contacts. There are no keyboard symbols for limit, float, or pressure switches. The processor doesn't know what is

closing a switch, only that it is open or closed. Contacts are assigned numbers to distinguish them.

Because elementary ladder diagrams (refer to units 4 and 5) follow a logical process, programming a PC should not be difficult. For example, a three-wire, start-stop control circuit is shown in figure 58-7A. Figure 58-7B shows how this same circuit will appear as it is programmed into the processor, through the program operator terminal. Figure 58-5 shows how these component parts are connected to the input/output (I/O) modules. Note that the starter has been rewired to bring the overload contact to the left control side. The maintaining contact is an "internal relay" of the PC. Note also in figure 58-7B that the normally closed stop button and the normally closed overload contact appear as normally open. Since terminal 1 and 3 are normally closed contacts, power will be fed to the input module, or track. When this occurs to the input module, the central processor interprets it as an instruction to change the terminal position of the contact that matches the terminal number of the input module. Contacts 1 and 3 are considered closed by the processor during normal operation, because power is fed through the normally closed contacts. Because a coil will always end the line of a program, overload contact 3 is moved to the left of the coil, where you would place any contact that controls the coil. Note the programmer coil symbol looks like this: (). After a circuit is energized, these symbols will assume a cross-hatch shading, or other distinctive feature as shown in figure 58-9. This tells you that the contacts are closed properly and the coil is energized. This feature is also useful for troubleshooting the control system in case of a malfunction.

Figure 58-10 illustrates the actual motor starter connection just described. All I/O module wiring is brought down to the terminal board connections and marked. The operator terminal is plugged into the bottom of the central processor unit. The motor starter is on the student motor control laboratory panel at the right.

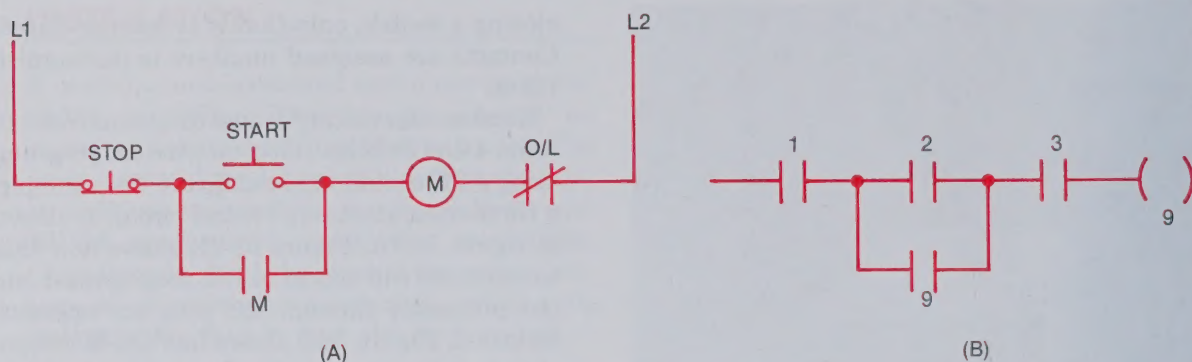


FIG. 58-7 (A) A three-wire electromagnetic ladder diagram circuit. (B) As it appears on the program operator terminal.

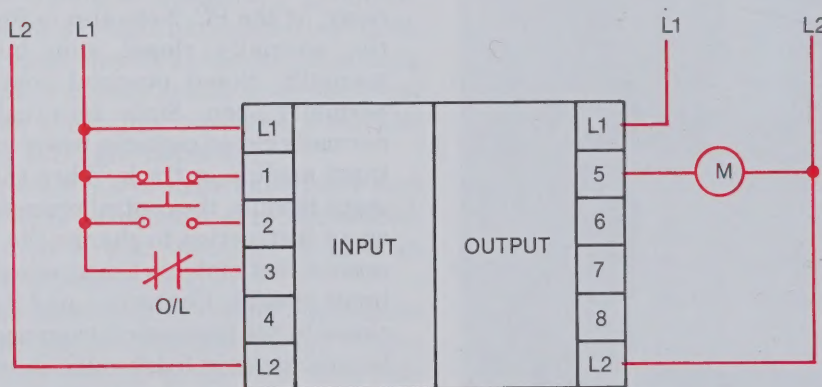


FIG. 58-8 PC connections for start-stop station

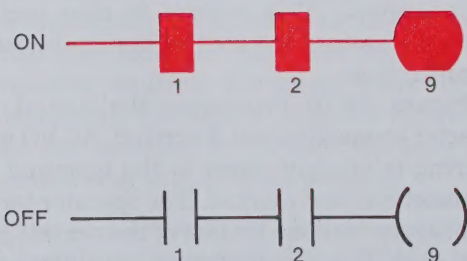


FIG. 58-9 Program operator display of a coil circuit

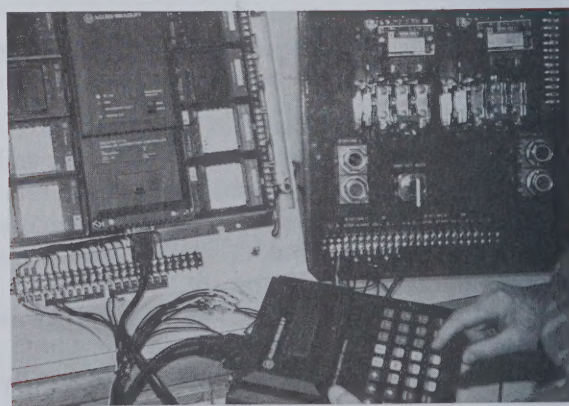


FIG. 58-10 PC connected to a motor starter on a student work panel (Courtesy of Terry Cunningham and Hiroshi Uchida, Los Angeles Trade-Technical College)

Different manufacturers use different methods of programming their controllers. Therefore, it is necessary to study and follow the instruction manual that accompanies a programmable controller.

MOTOR CONTROL CENTER

A modern motor control center combines the latest automation technologies, such as programmable controllers, solid-state starters, and ac and dc variable speed drives, in a common enclosure. One center is shown in figure 58-11. The control center receives incoming power and distributes it to all motors under a controlled and protected process from one location. See figure 58-12. This center is especially convenient for PC installations with many inputs and outputs. Existing electromagnetic motor control centers are readily adapted to PC control. The wiring is already installed to terminal blocks. The control center is simply rewired to a PC.

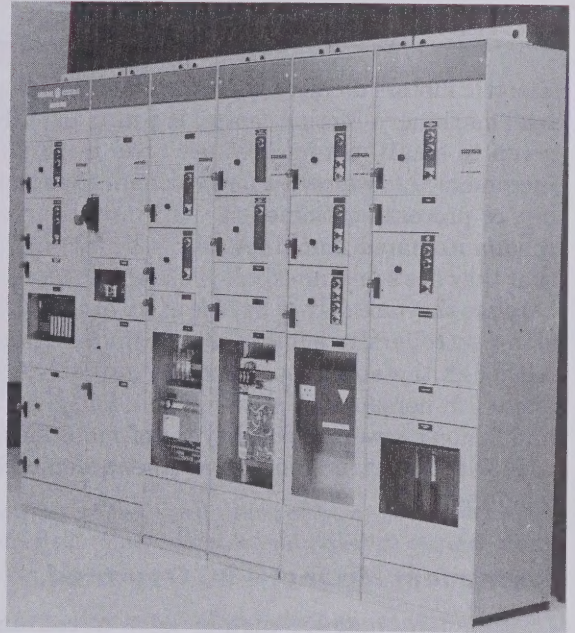


FIG. 58-11 Modern motor control center (Courtesy of General Electric Co., Factory Automation Products Division)

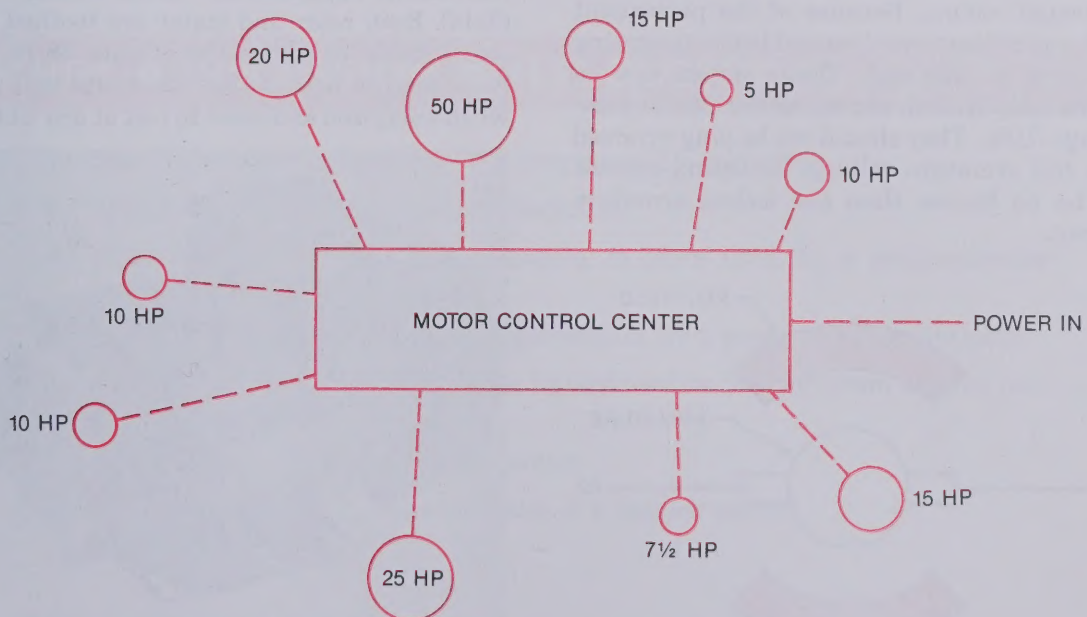


FIG. 58-12 Underground distribution of a motor control center (floor plan). Motor circuits may be run overhead also.

MOTION CONTROL

Electric motors do more than turn heavy industrial machinery. Motion control is a term usually given to small motors that are used for small incremental movements, for positioning, assembly, or processing. Some are used in industrial robot/automated machines. Many are so small that they are sometimes called electronic motors because they are driven by fine electronic, precision controllers to achieve precise movements. Although the size of such motors may start at about 1/8 horsepower, some range as high as 2 and 5 horsepower. Several types of motors are used with industrial robots and other automated machinery.

Permanent Magnet—DC Operated

Permanent magnet motors have a conventional wound armature with a commutator and brushes and a permanent magnetic field, figure 58-13. This motor has excellent starting torque with speed regulation just under that of compound motors. Because of the permanent field, motor losses are less and better operating efficiency is obtained. These motors can be dynamically braked, and can be reversed at a low voltage (10%). They should not be plug-reversed with full armature voltage. Reversing current can be no higher than the locked armature current.

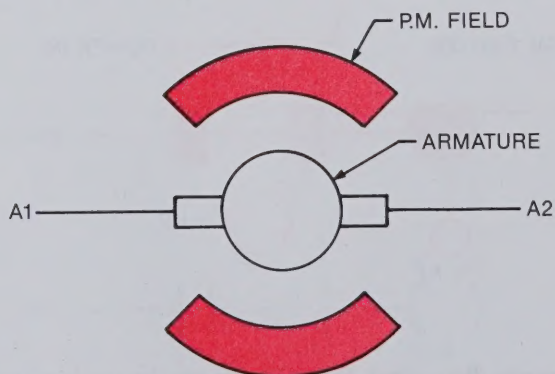


FIG. 58-13 Dc permanent magnet motor

Permanent Magnet Synchronous Motor—AC

Permanent magnet synchronous motors are ac motors that eliminate the slip characteristic of induction motors, figure 58-14. They operate at exactly the synchronous speed of the three-phase power speed, usually 1800 or 3600 rpm. High-density magnets are imbedded in the rotor. Permanent magnet synchronous ac motors are ideally suited for processes requiring accurate speed control or synchronizing of several interconnected operations.

STEPPER MOTORS

The stepper or stepping motor is a precision electromechanical incremental actuator. It uses the digital (on/off) approach for control of industrial machines. It delivers precise incremental motions of great accuracy. Its popularity is broadened by using it with programmable controllers. The stepper motor is dc with a permanent magnet rotor and a wound stator (field). Both rotor and stator are toothed, like small fields in themselves, figure 58-15. The basic feature here is that the motor will move when energized and come to rest at any number

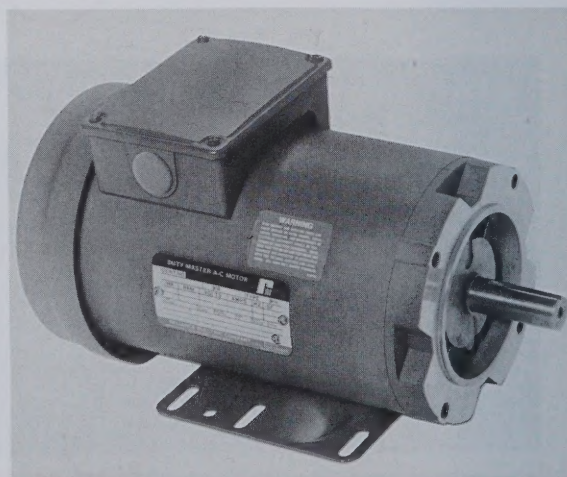


FIG. 58-14 Permanent magnet synchronous ac motor (Courtesy of Reliance Electric)

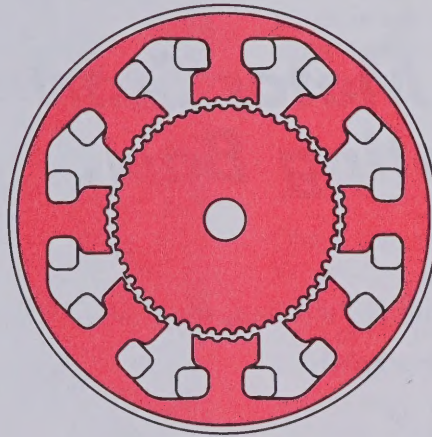


FIG. 58-15 Cross section of a typical stepper motor showing the toothed construction of the armature and stator. Signal pulses in serial order advancing sequentially from one field to an adjacent field drive the stepper motor.

of steps, in either direction. It is adequate for light loads and PC driven applications, and for positioning applications in many forms. It moves and stops according to the digital commands

from the PC. The stepper motor converts programmed digital pulse inputs into a series of motions; sequential, fast or slow, forward, and reverse.

STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Sketch the major components of a programmable controller.
2. Briefly describe a programmable controller.
3. What familiar method of programming is often used for a programmable controller?
4. Discuss some basic installation requirements for a programmable controller.
5. What is the major advantage of the lighted “on” or “off” program entered into the program terminal?
6. What is a modern motor control center?
7. What are the primary characteristics of a stepper motor?

UNIT 59 Motor Startup and Troubleshooting Basics

Objectives After studying this unit, the student will be able to:

- Demonstrate safe working habits
- Prepare motors for start up
- Start up newly installed motors
- Troubleshoot motors using basic sense faculties
- Separate circuit operation into logical steps for troubleshooting
- Use industrial control index for troubleshooting tips
- Seat new motor brushes, ac and dc
- Test a solid-state diode
- Change solid-state control modules according to the direction of a visual control panel

WARNING

High voltage and rotating parts may cause serious or fatal injuries. Installation, operation and maintenance of electrical machinery should be performed by qualified people!

All maintenance and repairs should be made with good, deliberate safety practices in mind. Fundamental to any job approach is a good safety procedure. Remember, SAFETY FIRST, THE JOB IS SECOND!

MOTOR STARTUP

After new motors and controls are installed, they should be checked for operation under load for

an initial period of at least one hour. During this time, the electrician can observe if any unusual noise or hot spots develop. The operating current must be checked against the nameplate ampere rating. This requires skill in the proper connection, setting and reading of an ammeter. The preferred ammeter is the type that has the clamp around the wire, figure 59-1. The nameplate ampere reading times the service factor (if any) sets the limits of the steady current; this value should not be exceeded.

If the motor has not been installed in a clean, well-ventilated place, clean the area. Good housekeeping, as well as direct accident and fire prevention techniques, must be emphasized at all times.

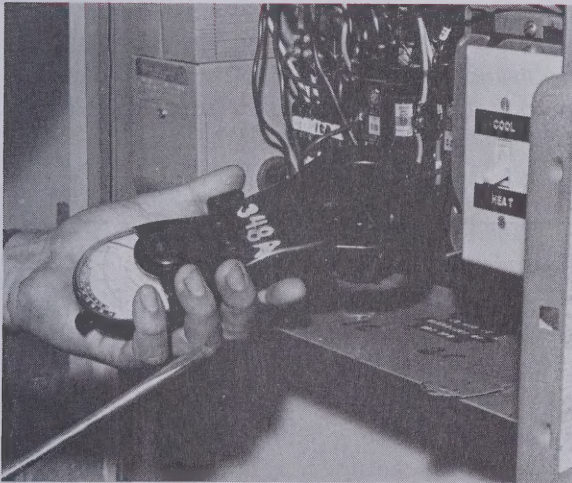


FIG. 59-1 Using an ammeter around a wire
(Courtesy Los Angeles Trade-Technical College, Los Angeles, CA)

MOTOR MOUNTS

Motor mounts must be checked to be sure that they are secure and on a firm foundation, figure 59-2. If necessary, add grout to secure the mounts. Ball-bearing motors can be mounted on sidewalls or the ceiling, vertically or horizontally.

Rotate the end shields to place grease fittings, plugs, or any openings in the best, or most accessible, location. Oil or grease the bearings if necessary.

NAMEPLATE

Check the power supply against the nameplate values; they should agree. Most motors will operate successfully with the line voltage within 10% (plus or minus) of the nameplate value; or within 5% of the frequency (Hertz). Most 220-volt motors can be used on 208-volt network systems but with slightly modified performance. Generally 230-volt motors should not be used on 208-volt systems.

To reconnect a dual-voltage motor to a desired voltage, follow the instructions on the connection diagram on the nameplate. (See also Unit 4 of this text, “The Interpretation and Application of Simple Wiring and Elementary Diagrams.”)

Motor starter overload relay heaters must be installed with the proper size. The motor will not run without them. Sizing information is found inside the control enclosure cover. The starting fuses should be checked in a similar manner. The selection of the correct fuse size must be in accor-

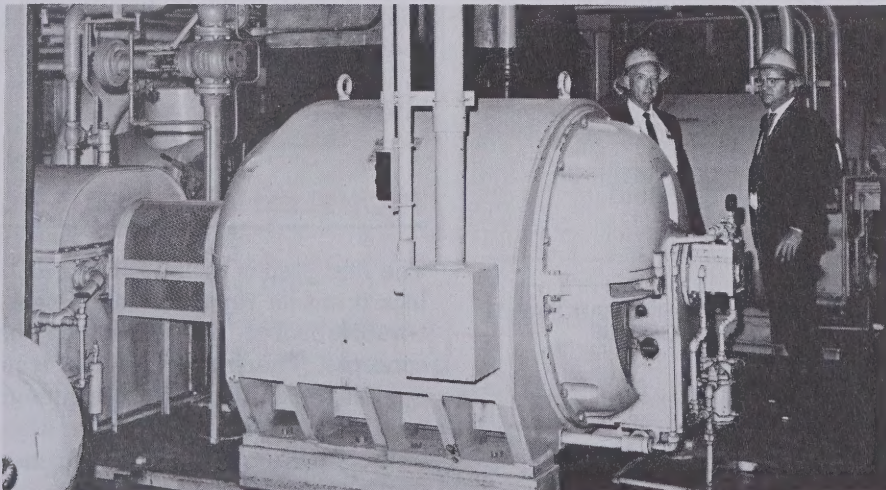


FIG. 59-2 A motor on a firm, secure foundation

dance with the National Electrical Code or with local requirements.

Collector Rings and Commutators

The collector rings on wound rotor motors are sometimes coated with a film at the factory to protect them while in stock and during shipment. The brushes may be fastened in a raised position. Before putting the motor into service, the collector ring surface must be cleaned of the protective coating. The brushes then must be set down on the collector ring or commutator. When the motor is in service, keep the rings clean and maintain their polished surfaces. Chocolate brown is a good operating color for commutators. Ordinarily, the rings will require only occasional wiping with a piece of canvas or nonlinting cloth. Do not let dust, dirt, moisture, or oil accumulate between the collector rings.

Brushes

Brushes should move freely in the holders. At the same time, they must make firm, even contact with the collector rings and commutators. When installing new brushes, fit them carefully to the collector rings. Be sure that the

pigtail conductors are securely fastened to, and make good contact with, the brush holders. It may be necessary to “sand-in” brushes to fit the contour of commutator or slip rings, figure 59-3.

LOADS

Electrical

A close check on operating line voltages, both at the incoming line and close to the motor terminals, may reveal unbalances that can be corrected. An unbalanced three-phase electrical system can cause trouble. Avoid unbalanced single-phase loading on a three-phase distribution panel. Check for required surge suppressors for solid-state devices.

Mechanical

Operate the motor without a load to check rotation and free running action. The desired direction of rotation is the required direction of rotation of the driven load. Incorrect rotation direction of some gear boxes, machines and equipment may cause severe damage. To reverse rotation of a three-phase motor, interchange any two line leads. To reverse rotation of a single-phase motor, follow the connection diagram. The connected loads should be well-balanced to reduce vibration. A smooth-running machine is much more efficient and will cause less trouble later.

TROUBLESHOOTING BASICS

The first step is to shut down the machine and lock it out for repair or adjustment. The expert troubleshooter has mastered basic circuit concepts. The most valuable troubleshooting asset is the ability to apply common sense when analyzing a control operation. Also, good maintenance personnel learn to use sensory functions to diagnose and locate trouble.

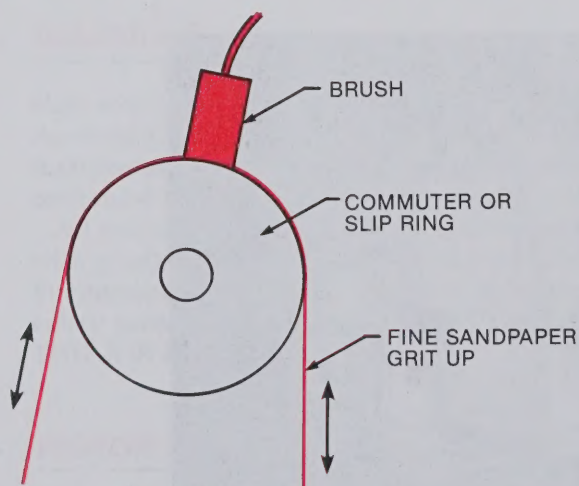


FIG. 59-3 Fitting a brush in place

- **LOOKING** may reveal contacts stuck and hung up, thereby creating open circuits.
- **LISTENING** may indicate loose parts, faulty bearings, excessive speed, etc.
- **SMELLING** may indicate burning insulation or a coil failure.
- **TOUCHING** may reveal excessive motor shaft play, vibration, or abnormal heat.

This seemingly over-simplified procedure to locating a problem has saved many hours of labor. Consider the length of time it would take to become thoroughly familiar with a complicated schematic diagram, compared with locating a few contacts that are stuck — the result of merely **LOOKING**.

However, finding a problem in an installation is not usually this easy. An orderly, step-by-step approach is required. Circuit operation is separated in logical parts. Circuits and components are then divided into smaller parts to determine their functions, relationships to one another, and the effect that they have on each other in the over-all control system operation. Each step leads to the source of the difficulty, finally pinpointing the problem. This procedure may require the use of a voltage tester, ammeter, multimeter, jumper wires, and other tools.

Check the power supply to see if it is on and if it is correct. Test all protective devices. If the coil as shown in figure 59-4 does not energize, a jumper wire can be placed from L1 to 3 of the

control circuit. By jumping across the contacts of the limit switch and push buttons, the circuit operation is separated into logical parts. If the starter coil is now energized, the problem may be in the limit switch, stop, or start push buttons. Smaller circuits and components are now tested by “jumping” around the limit switch, for example. We may then go to the control station, if necessary. By an orderly process of elimination, by testing all possible fault areas, the problem can be located accurately and efficiently.

Indiscriminate jumping, however, should not be practiced because of the danger of short circuits. For example, a jumper should never be placed across a power-consuming device, such as a contactor coil; voltage or ohmmeter testers are used in this instance. If an ohmmeter is used to test a coil for continuity, the power must be off.

Tables 59-1 and 59-2 are provided as aids to servicing electric control equipment. Use Table 59-1 as an index. Then refer to 59-2 for signs and solutions. For example, if the problem involves an ac contactor, look under the heading **Contactors, Ac operated**. In the parenthesis next to it, are specific number references (1-12). Refer to Table 59-2, items 1 through 12 for the signs and solutions to Ac operated contactor problems. Study questions appear on page 331.

Since downtime of a machine may be expensive, the best guideline is to select and replace top quality devices designed for specific applications.

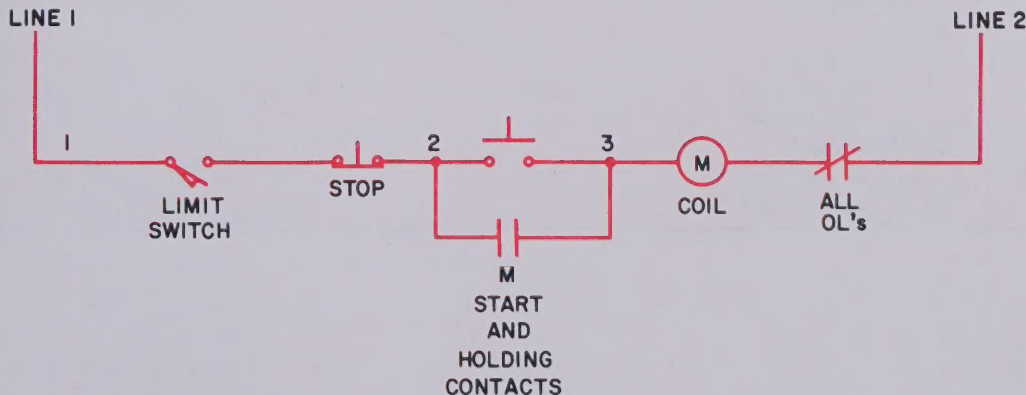


FIG. 59-4 Control circuit for a troubleshooting exercise

TABLE 59-1 Industrial Controls Index to Troubleshooting Suggestions

TYPE OF CONTROL	REFERENCE TO CONTROL SIGNS/SOLUTIONS
Electrically Operated Devices	
I. Magnetically Operated Device	
A. Contactors	
1. Ac	
a. Ac operated	(1-12)
b. Dc operated	(5-13)
2. Dc	(5-13)
B. Relays	
1. Ac	
a. Simple magnetic	(1-12)
b. Timing (mechanical escapement type)	(14, 15)
c. Overcurrent	
(1) Instantaneous	(16, 17)
(2) Inverse-time	(16-19)
2. Dc	
a. Simple magnetic	(5-13)
b. Timing	
(1) Mechanical escapement	(14, 15)
(2) Decay-of-flux	(7-13, 20, 21)
(3) Capacitor	(7-13, 22, 23)
c. Overcurrent	
(1) Instantaneous	(16, 17)
(2) Inverse-time	(16-19)
C. Solenoids	
1. Ac operated	(24-30)
2. Dc operated	(28-31)
D. Valves	
1. Ac operated	(27, 32-35)
2. Dc operated	(34-36)
E. Brakes	
1. Shoe brake	
a. Ac operated	(24-30, 37-41)
b. Dc operated	(28-31, 38-41)
2. Disc brake	
a. Ac operated	(21, 26, 37-41)
b. Dc operated	(12, 31, 38-41)

TABLE 59-1 Industrial Controls Index to Troubleshooting Suggestions (Continued)

TYPE OF CONTROL	REFERENCE TO CONTROL SIGNS/SOLUTIONS
Electrically Operated Devices	
II. Motor-Operated Devices	
A. Relays	
1. Timing	(11, 15, 42, 43)
2. Induction disc or cup type	(11, 44)
B. Brakes	
1. Thrustor operated	(38–41, 45)
C. Thrustors	(45)
D. Valves	
1. Thrustor operated	(35, 45, 46)
2. Geared	(35, 46)
E. Rheostats	(11, 47, 48)
III. Thermally Operated Devices	
A. Relays	(11, 49–52)
B. Thermostats	
1. Bimetallic	(11, 53)
2. Expanding fluid (bulb and bellows)	(11, 52, 54, 55)
IV. Static Accessories	
A. Resistors	(11, 56–58)
B. Rectifiers (dry type)	(59)
C. Capacitors	(60)
D. Transformers	(61, 62)
E. Fuses	(63, 64)
Mechanically Operated Devices	
I. Manually Operated Devices	
A. Master switches	(11, 52, 65)
B. Drum controllers	(8, 11, 52, 65–67)
C. Pushbuttons	(11, 52, 65, 68, 69)
D. Selector switches	(11, 52, 65, 68, 69)
E. Knife switches	(70)
F. Manual starters	
1. Full voltage (small sizes)	(8, 11, 49, 50, 65)
2. Reduced voltage	(8, 11, 49, 50, 65)
G. Rheostats	(11, 47, 48)
H. Manual contactors	(8, 11, 65)
II. Otherwise Mechanically Operated Devices	
A. Limit switches	(8, 11, 52, 71)
B. Speed-sensitive switches	(11, 14, 52, 71)
C. Float switches	(11, 14, 52, 65)
D. Flow switches	(11, 14, 52, 65, 72)
E. Pressure switches	(11, 14, 52, 65, 72)

TABLE 59-2 Industrial Control Troubleshooting Tips

CONTROL SYMPTOMS	POSSIBLE CAUSES AND THINGS TO INVESTIGATE
1. Noisy magnet	Broken pole shaver; magnet faces not true as result of wear or mounting strains; dirt on magnet faces
2. Broken pole shaver	Heavy slamming caused by overvoltage, weak tip pressure, wrong coil
3. Coil failure	Moisture; overvoltage; high ambient; failure of magnet to seal in on pickup; too rapid duty cycle; corrosive atmosphere; chattering of magnet; metallic dust
4. Wear on magnet	Overvoltage; broken pole shaver; wrong coil; weak tip pressure; chattering
5. Blowout coil overheats	Overcurrent; wrong size of coil; loose connections on stud or tip; tip heating (see Table 1); excess frequency
6. Pitted, worn, or broken arc-chutes	Abnormal interrupting duty (inductive load); excessive vibration or shock; moisture; improper assembly; rough handling
7. Failure to pick up	Low voltage; coil open; mechanical binding; no voltage; wrong coil; shorted turns; excessive magnet gap
8. Contact-tip troubles	Do not file silver tips. Rough spots or discoloration will not harm efficiency
Filing or dressing	
Interrupting excessively	Check for grounds, shorts, or excessive motor currents
high current	
Excessive jogging	Install larger device rated for jogging service
Weak tip pressure	Replace contacts and springs; check carrier for damage
Dirt on surfaces	Clean contacts with Freon; reduce exposure
Short circuits or ground	Remove fault; be sure fuse/breaker size is correct
fault	
Loose connection	Clean, then tighten
Sustain overload	Check for excessive motor current or install larger device
9. Broken flexible shunt	Large number of operations; improper installation (check instructions); extreme corrosive conditions; burned from arcing
10. Failure to drop out	Mechanical binding; gummy substance on magnet faces; air gap in magnet destroyed; contact tip welding; weak tip pressure; voltage not removed
11. Insulation failure	Moisture; acid fumes; overheating; accumulation dirt on surfaces; voltage surges; short circuits
12. Various mechanical failures	Overvoltage; heavy slamming (see 2); chattering; abrasive dust
13. Coil failure	Overvoltage; high ambient; wrong coil; moisture; corrosive atmosphere; intermittent coil energized continuously; holding resistor not cut in

TABLE 59-2 Industrial Control Troubleshooting Tips (Continued)

CONTROL SYMPTOMS	POSSIBLE CAUSES AND THINGS TO INVESTIGATE
14. Sticking	Dirt; worn parts; improper adjustment; corrosion; mechanical binding
15. Mechanical wear	Abrasive dust; improper application (in general not suited for continuous cycling).
16. Low trip	Wrong coil; assembled wrong
17. High trip	Mechanical binding; wrong or shorted coil; assembled wrong
18. Fast trip	Fluid out or too light; vent too large; high temperature; wrong heaters
19. Slow trip	Fluid too heavy; vent too small; mechanical binding; dirt; low temperature; wrong heaters
20. Too-short time	Dirt in air gap; shim too thick; too much spring and tip pressure; misalignment
21. Too-long time	Shim too thin; weak spring and tip pressure (use brass screws for steel backed shims); gummy substance on magnet faces
22. Too-short time	Same as 20, plus not enough capacitance; not enough resistance
23. Too-long time	Same as 21, plus too much capacitance, too much resistance
24. Noisy magnet	Same as 1, plus low voltage; mechanical overload; load out of alignment
25. Broken pole shader	Heavy slamming caused by overvoltage; mechanical underload; wrong coil; low frequency
26. Coil failure	Same as 3, plus mechanical overload (can't pick up); mechanical underload (slam); mechanical failure
27. Wear on magnet	Overvoltage; underload; broken pole shader; wrong coil; chattering; load out of alignment
28. Failure to pick up	Same as 7, plus mechanical overload
29. Failure to drop out	Mechanical binding; gummy substance on magnet faces; air gap in magnet destroyed; voltage not removed; contacts welded
30. Miscellaneous mechanical failures	Same as 12, plus underload
31. Coil failure	Same as 13, plus mechanical failure of coil
32. Noise	Same as 1, plus water hammer
33. Coil failure	Same as 3, plus handling fluid above rated temperature
34. Failure to open or close	Similar to 28, 29, plus corrosion; scale; dirt; operating above rated pressure

TABLE 59-2 Industrial Control Troubleshooting Tips (Continued)

CONTROL SYMPTOMS	POSSIBLE CAUSES AND THINGS TO INVESTIGATE
35. Leaks and mechanical failure ...	Worn seat; solid matter in seat (check strainer ahead of valve)
36. Coil failure	Same as 13, plus handling fluid above rated temperature
37. Noisy magnet	Same as 2, plus improper adjustment (too much pressure or incorrect lever ratio)
38. Excess wear or friction	Abrasive dust; heavy-duty; high inertia load; excess temperature; scarred wheels
39. Failure to hold load	Worn parts; out of adjustment; misapplication; failure to use recommended substitute parts
40. Failure to set	Improper adjustment; mechanical binding; coil not de-energized; worn parts
41. Failure to release	Improper adjustment; coil not energized; mechanical binding; low voltage or current; coil open; shorted turns
42. Failure to time out	Mechanical binding; worn parts; motor damaged; no voltage on motor; dirt
43. Failure to reset	Mechanical binding; worn parts; dirt
44. Failure to operate properly	Coils connected wrong; wrong coils; mechanical binding
45. Short life of thruster	Abrasive dust; dirty oil; water in tank
46. Failure to open or close	Corrosion; scale; dirt; mechanical binding; damaged motor; no voltage
47. Wear on segments or shoes	Abrasive dust; very heavy duty; no lubrication (special materials available)
48. Resistor failure	Overcurrent; moisture; corrosive atmospheres
49. Failure to trip (motor burnout)	Heater incorrectly sized; mechanical binding; relay previously damaged by short circuit current; dirt; corrosion; motor and relay in different ambient temperatures
50. Failure to reset	Broken mechanism; corrosion; dirt; worn parts; resetting too soon
51. Trips too low	Wrong heater; relay in high ambient (check temperature of motor)
52. Burning and welding of control contacts and shunts	Short circuits on control circuits with too large protecting fuses; severe vibration; dirt; oxidation

TABLE 59-2 Industrial Control Troubleshooting Tips (Continued)

CONTROL SYMPTOMS	POSSIBLE CAUSES AND THINGS TO INVESTIGATE
53. Arcing and burning of contacts . .	Misapplied; should handle very little current and have sealing circuit
54. Bellows distorted	Mechanical binding; temperature allowed to overshoot
55. Bulb distorted	Liquid frozen in capillary tube
56. Overheating	Used above rating; running on starter resistor
57. Corrosion	Excess moisture; salt air; acid fumes
58. Breakage, distortion and wear	Overheating; mechanical abuse; severe vibration; shock
59. Breakdown	High temperature; moisture; overcurrent; overvoltage; corrosive atmosphere; mechanical damage
60. Breakdown	Overload; overvoltage; ac on dc capacitor; moisture; high temperature; mechanical damage; continuous voltage on intermittent types
61. Overheating	Overload; overvoltage; intermittent-rating device operated too long
62. Insulation failure	Overheating; overvoltage; voltage surges; moisture; mechanical damage
63. Premature blowing	Extra heating from outside; copper oxide on ferrules and clips (plated ferrules and clips are available); high ambient
64. Too slow blowing	Wrong sized fuse for application
65. Mechanical failures	Abrasive dust and dirt; misapplication; mechanical damage
66. Short contact life	Jogging; handling abnormal currents; lack of lubrication where recommended; abrasive dirt
67. Flashover	Jogging; short circuits; handling too large motor; moisture; acid fumes; gases; dirt
68. Failure to break arc	Too much current; too much voltage; (usually dc); misapplication; too much inductance
69. Failure to make contact	Mechanical damage; dirt; corrosion; wear allowance gone
70. Heating	Overcurrent; loose connection; spring clips loose or annealed; oxidation; corrosion
71. Mechanical failure	Same as 65, plus excessive operating speed
72. Leaks	Corrosion; mechanical damage; excessive pressure

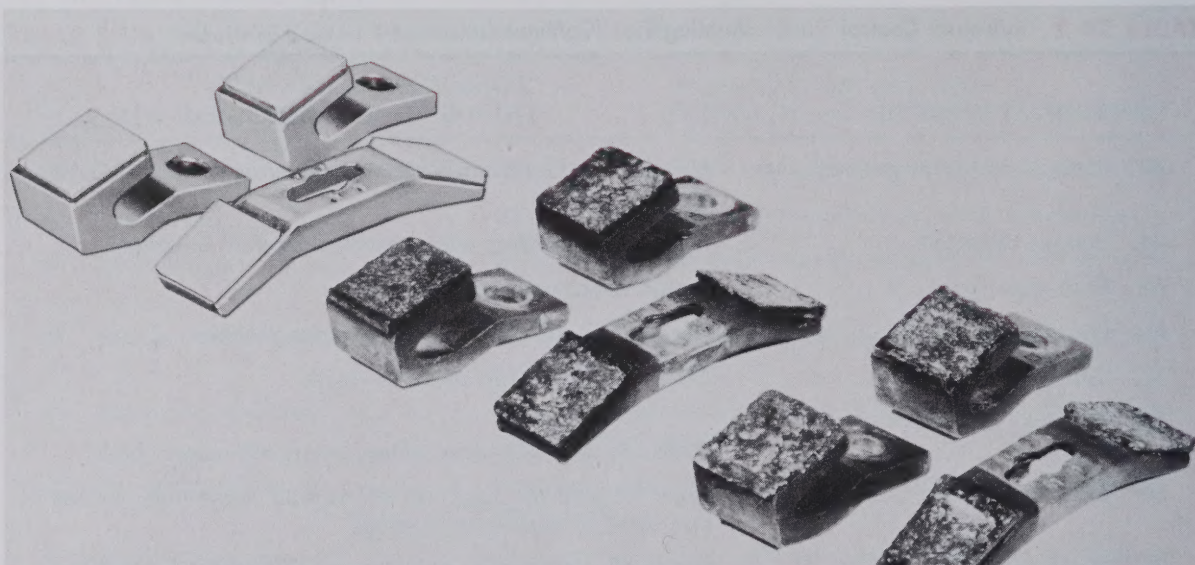


FIG. 59-5 Replacement guides for life of contact tips. Left: new or excellent contacts. Center: worn contacts, a signal to watch. Right: excessively worn, change (Courtesy Square D Co.)

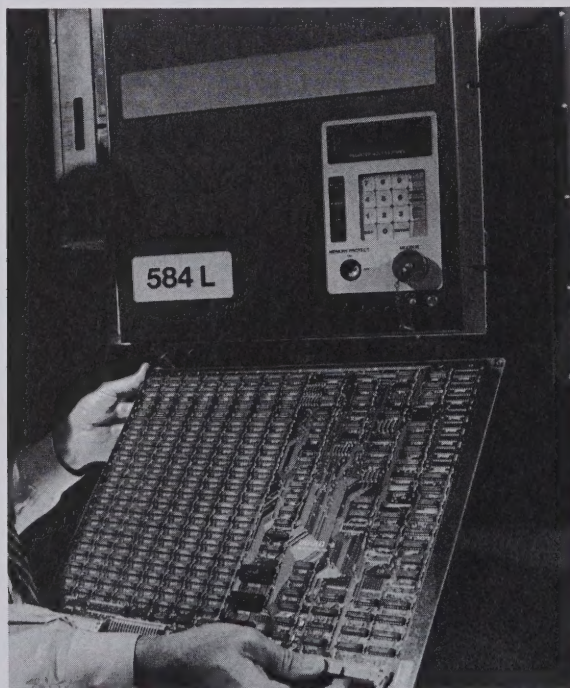


FIG. 59-6 Troubleshooting complex systems is simplified by modular construction. This industrial process controller has removable circuit boards to allow for troubleshooting and also for convenient upgrading of capabilities. (Courtesy of Gould Inc., Industrial Automation Systems)

SOLID-STATE EQUIPMENT

Modular construction makes troubleshooting easier. On large controllers, components can be removed for repair or replacement. Leads disconnect simply by means of plug connectors. Figure 59-6 shows an industrial processor controller, which features the convenient drawout construction of all elements including circuit boards.

With self-diagnostics on some controllers, each of the circuit boards is checked by the microprocessor. As each board passes the self-test routine, this information is displayed on the visual control panel. The panel tells where any

problems are located. The malfunctioning modules or circuit boards are then replaced. For electronic equipment, always follow the manufacturer's recommendations about service so as not to void a new equipment guarantee.

With total failures, all fuses should be tested first. If the failure still exists, the power diodes in the converter can be readily tested with an ohmmeter. Remember, these solid-state devices pass current in one direction only. If no continuity is found in either direction of the diode, the diode is open. If continuity exists in both directions, the diode is shorted. In either instance, the diode must be replaced.

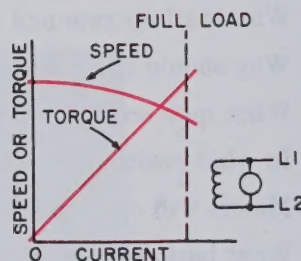
STUDY ■ DISCUSSION ■ TEST QUESTIONS

1. Who shall operate and maintain electrical machinery?
2. Why should the motor be run for a period of time following checkout?
3. What may occur if a jumper is placed across coil M in figure 59-3?
4. In what position do ball-bearing motors function?
5. Motors will operate satisfactorily at what percent over and under voltage?
6. What basic sensory faculties should a troubleshooter rely on?
7. What is an orderly step-by-step procedure in successful troubleshooting?
8. What might be a hazard if a motor is started in the wrong direction?
9. When a coil does not pick up, what are the probable causes?
10. What are the probable causes of a noisy magnet?
11. Why are some solid-state controllers easy to troubleshoot?
12. How is a solid-state diode tested? Explain.

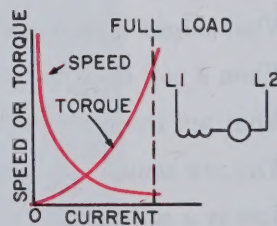
APPENDIX A

MOTOR TYPES AND LINE DIAGRAMS

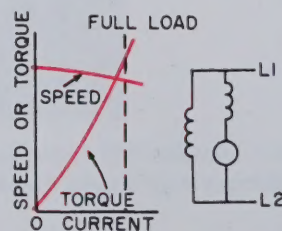
Dc Shunt Motor. Main field winding is designed for parallel connection to the armature; stationary field; rotating armature with commutator; has a no-load speed; full speed at full load is less than no-load speed; torque increases directly with load.



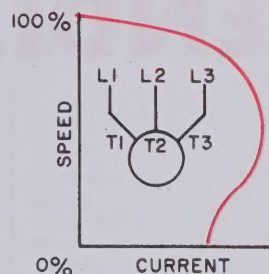
Dc Series Motor. Main field winding is designed for series connection to the armature; stationary field; rotating armature with commutator; does not have a no-load speed; requires solid direct connection to the load to prevent runaway at no-load; speed decreases rapidly with increase in load; torque increases as square of armature current; main motor for crane hoists; excellent starting torque.



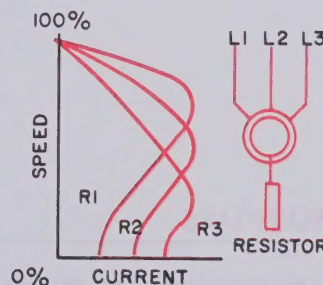
Dc Compound Motor. Main field both shunt (parallel) and series; stationary field; rotating armature with commutator; combination shunt and series fields product characteristics between straight shunt or series dc motor; good starting torque; main motor for dc driven machinery (mills or presses).



Ac Squirrel Cage Motor. Single or three phase; single phase requires a starting winding; three phase, self starting; stationary stator winding; no electrical connection to short-circuited rotor; torque produced from magnetic reaction of stator and rotor fields; speed a function of supply frequency and number of electrical poles wound on stator; considered as constant speed even though speed decreases slightly with increased load; good starting torque; high inrush currents during starting on full voltage; rugged construction; easily serviced and maintained; high efficiency; good running power factor when delivering full load; requires motor control for stator windings only.



Ac Wound-Rotor Induction Motor. Characteristics similar to squirrel cage motor; stationary stator winding; rotor windings terminate on slip rings; external addition of resistance to rotor circuit for speed control; good starting torque; high inrush current during starting on full voltage; low efficiency when resistor is inserted in rotor windings; good running power factor; requires motor controls for stator and rotor circuits.



Ac Synchronous Motor. Stationary ac stator windings; rotating dc field winding; no starting torque unless motor has starting winding; generally poor starting torque; constant speed when motor up to speed and dc field winding energized; can provide power factor correction with proper dc field excitation; requires special motor control for both ac and dc windings to prevent the dc field winding from being energized until a specified percent of running speed has been obtained.

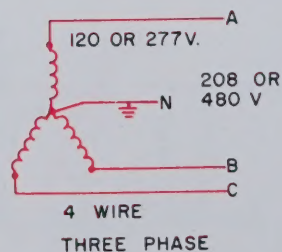
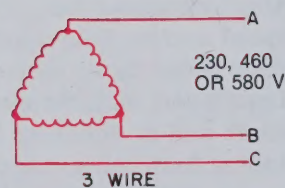
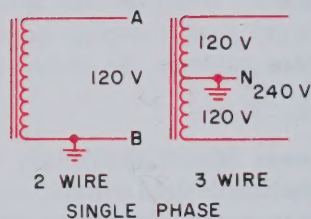
APPENDIX B

POWER SUPPLIES

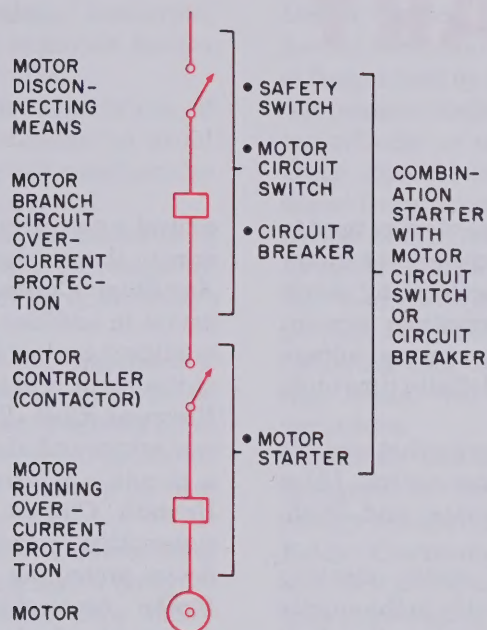
All electrical power supplied as ac or dc; primarily ac; generation, transmission, and some distribution of power at high voltage (above 5000 volts) or medium voltage (600 to 5000 volts); most power distribution of voltage for industrial and residential use is 600 volts and under; ac power generally at 60-Hertz frequency; ac distribution at use location single or three phase.

Single-phase. Two wire, 120 volts, one line grounded; 120/240 volts, three-wire center-line grounded; residential distribution, lighting, heat, fractional horsepower motors and business machines.

Three-phase. Three-wire delta 230/460 volts, 580 volts; four-wire wye 208/440, 277/480 volts neutral line grounded; primary industrial power distribution; many motor drives, integral horsepower motors, lighting, heating, fractional horsepower motors, and business machines; used as three-phase or single-phase power supply.



MOTOR CIRCUIT ELEMENTS



GLOSSARY

Accelerating Relay Any type of relay used to aid in starting a motor or to accelerate a motor from one speed to another. Accelerating relays may function by: motor armature current (current limit acceleration); armature voltage (counter emf acceleration); or definite time (definite time acceleration).

Accessory (control use) A device that controls the operation of magnetic motor control. (Also see Master Switch, Pilot Device, and Push-button.)

Across-the-line Method of motor starting which connects the motor directly to the supply line on starting or running. (Also called Full Voltage Control.)

Alternating Current (Ac) Current changing both in magnitude and direction; most commonly used current.

Ambient Temperature The temperature surrounding a device.

Ampacity The maximum current rating of a wire or cable.

Ampere Unit of electrical current.

Analog Signal Having the characteristic of being continuous and changing smoothly over a given range, rather than switching on and off between certain levels.

ASA American Standards Associations.

Automatic Self-acting, operating by its own mechanism when actuated by some triggering signal; for example, a change in current strength, pressure, temperature, or mechanical configuration.

Automatic Starter A self-acting starter which is completely controlled by master or pilot switches or other sensing devices; designed to

control automatically the acceleration of a motor during the acceleration period.

Auxiliary Contacts Contacts of a switching device in addition to the main circuit contacts; auxiliary contacts operate with the movement of the main contacts.

Blowout Coil Electromagnetic coil used in contactors and starters to deflect an arc when a circuit is interrupted.

Branch Circuit That portion of a wiring system that extends beyond the final overcurrent device protecting the circuit.

Brake An electromechanical friction device to stop and hold a load. Generally electric release spring applied — coupled to motor shaft.

Breakdown Torque (of a motor) The maximum torque that will develop with the rated voltage applied at the rated frequency, without an abrupt drop in speed. (ASA)

Busway A system of enclosed power transmission that is current and voltage rated.

Capacitor-Start Motor A single-phase induction motor with a main winding arranged for direct connection to the power source and an auxiliary winding connected in series with a capacitor. The capacitor phase is in the circuit only during starting. (NEMA)

Circuit Breaker Automatic device which opens under abnormal current in carrying circuit; circuit breaker is not damaged on current interruption; device is ampere, volt, and horsepower rated.

Contact A conducting part which acts with another conducting part to complete or to interrupt a circuit.

Contactors A device to establish or interrupt an electric power circuit repeatedly.

Controller A device or group of devices that governs, in a predetermined manner, the delivery of electric power to apparatus connected to it.

Controller Function Regulate, accelerate, decelerate, start, stop, reverse, or protect devices connected to an electric controller.

Controller Service Specific application of controller. General Purpose: standard or usual service. Definite Purpose: service condition for specific application other than usual.

Current Relay A relay that functions at a predetermined value of current. A current relay may be either an overcurrent relay or an under-current relay.

Dashpot Consists of a piston moving inside a cylinder filled with air, oil, mercury, silicon, or other fluid. Time delay is caused by allowing the air or fluid to escape through a small orifice in the piston. Moving contacts actuated by the piston close the electrical circuit.

Definite Time (or Time Limit) Definite time is a qualifying term indicating that a delay in action is purposely introduced. This delay remains substantially constant regardless of the magnitude of the quantity that causes the action.

Definite-purpose Motor Any motor designed, listed, and offered in standard ratings with standard operating characteristics or mechanical construction for use under service conditions other than usual or for use on a particular type of application. (NEMA)

Device A unit of an electrical system that is intended to carry but not utilize electrical energy.

Digital The representation of data in the form of pieces, bits or digits.

Diode A two-element electronic device that permits current to flow through it in only one direction.

Direct Current (Dc) A continuous nonvarying current in one direction.

Disconnecting Means (Disconnect) A device, or group of devices, or other means whereby the conductors of a circuit can be disconnected from their source of supply.

Drum Controller Electrical contacts made on surface of rotating cylinder or sector; contacts made also by operation of a rotating cam.

Drum Switch A drum switch is a switch having electrical connecting parts in the form of fingers held by spring pressure against contact segments or surfaces on the periphery of a rotating cylinder or sector.

Duty Specific controller functions. Continuous (time) Duty: constant load, indefinite long time period. Short Time Duty: constant load, short or specified time period. Intermittent Duty: varying load, alternate intervals, specified time periods. Periodic Duty: intermittent duty with recurring load conditions. Varying Duty: varying loads, varying time intervals, wide variations.

Dynamic Braking Using the motor as a generator, taking it off the line and applying an energy dissipating resistor to the armature.

Eddy Currents Circular induced currents contrary to the main currents; a loss of energy that shows up in the form of heat.

Electrical Interlocking Accomplished by control circuits in which the contacts in one circuit control another circuit.

Electric Controller A device, or group of devices, which governs, in some predetermined manner, the electric power delivered to the apparatus to which it is connected.

Electronic Control Control system using gas and/or vacuum tubes or solid-state devices.

Enclosure Mechanical, electrical and environmental protection for control devices.

Eutectic Allow Metal with low and sharp melting point; used in thermal overload relays; converts from a solid to a liquid state at a specific temperature; commonly called solder pot.

Feeder The circuit conductor between the service equipment, or the generator switchboard of an isolated plant, and the branch circuit over-current device.

Feeler Gauge A precision instrument with blades in thicknesses of thousandths of an inch for measuring clearances.

Filter A device used to remove the voltage/current ripple produced by a rectifier.

Frequency Number of complete variations made by an alternating current per second; expressed in Hertz. (See Hertz)

Full Load Torque (of a motor) The torque necessary to produce the rated horsepower of a motor at full load speed.

Full Voltage Control (Across-the-line) Connects equipment directly to the line supply on starting.

Fuse An overcurrent protective device with a fusible member which is heated directly and destroyed by the current passing through it to open a circuit.

General Purpose Motor Any open motor having a continuous 40C rating and designed, listed, and offered, in standard ratings with standard operating characteristics and mechanical construction for use under usual service conditions without restrictions to a particular application or type of application. (NEMA)

Heat Sink Metal used to dissipate the heat of solid-state components mounted on it; usually finned in form.

Hertz International unit of frequency, equal to one cycle per second of alternating current.

High Voltage Control Formerly, all control above 600 volts. Now, all control above 5000 volts. See Medium Voltage for 600- to 5000-volt equipment.

Horsepower Measure of the time rate of doing work (working rate).

Impedance Total opposition to current flow in an electrical circuit.

Input Power delivered to an electrical device.

Instantaneous Instantaneous is a qualifying term indicating that no delay is purposely introduced in the action of the device.

Integral Whole or complete; not fractional.

Interface A circuit permitting communication between the central processing unit (of a programmable controller) and a field input or output.

Interlock To inter-relate with other controllers; an auxiliary contact. A device is

connected in such a way that the motion of one part is held back by another part.

Inverse Time A qualifying term indicating that a delayed action is introduced purposely. This delay decreases as the operating force increases.

Jogging (Inching) Momentary operations; the quickly repeated closure of the circuit to start a motor from rest for the purpose of accomplishing small movements of the driven machine.

Jumper A short length of conductor used to make a connection between terminals or around a break in a circuit.

Limit Switch A mechanically operated device which stops a motor from revolving or reverses it when certain limits have been reached.

Load Center Service entrance; controls distribution; provides protection of power; generally of the circuit breaker type.

Local Control Control function, initiation, or change accomplished at the same location as the electric controller.

Locked Rotor Current (of a motor) The steady-state current taken from the line with the rotor locked (stopped) and with the rated voltage and frequency applied to the motor.

Locked Rotor Torque (of a motor) The minimum torque that a motor will develop at rest for all angular positions of the rotor with the rated voltage applied at a rated frequency. (ASA)

Lockout A mechanical device which may be set to prevent the operation of a pushbutton.

Logic A means of solving complex problems through the repeated use of simple functions which define basic concepts. Three basic logic functions are: and, or, and not.

Low Voltage Protection (LVP) Magnetic control only; nonautomatic restarting; three-wire control; power failure disconnects service; power restored by manual restart.

Low Voltage Release (LVR) Manual and magnetic control; automatic restarting; two-wire control; power failure disconnects service; when power is restored, the controller automatically restarts motor.

Magnet Brake Friction brake controlled by electromagnetic means.

Magnetic Contactor A contactor which is operated electromechanically.

Magnetic Controller An electric controller; device functions operated by electromagnets.

Maintaining Contact A small control contact used to keep a coil energized, actuated by the same coil usually. Holding contact; Pallet switch.

Manual Controller An electric controller; device functions operated by mechanical means or manually.

Master Switch A main switch to operate contactors, relays, or other remotely-controlled electrical devices.

Memory Part of a programmable controller where instructions and information are stored.

Medium Voltage Control Formerly known as High Voltage; includes 600- to 5000-volt apparatus; air break or oil-immersed main contactors; high interrupting capacity fuses; 150,000 kVA at 2300 volts; 250,000 kVA at 4000-5000 volts.

Microprocessor A small computer.

Motor Device for converting electrical energy to mechanical work through rotary motion; rated in horsepower.

Motor Circuit Switch Motor branch circuit switch rated in horsepower; capable of interrupting overload motor current.

Motor-Driven Timer A device in which a small pilot motor causes contacts to close after a predetermined time.

Multispeed Starter An electric controller with two or more speeds; reversing or nonreversing; full or reduced voltage starting.

NEMA National Electrical Manufacturers Association.

NEMA Size Electric controller device rating; specific standards for horsepower, voltage, current, and interrupting characteristics.

Noise A condition that interferes with the desired voltage, or signal, in a circuit. Noise can produce erratic operation.

Nonautomatic Controller Requires direct operation to perform function; not necessarily a manual controller.

Nonreversing Operation in one direction only.

Normally Open and Normally Closed When applied to a magnetically-operated switching device, such as a contactor or relay, or to the contacts of these devices, these terms signify the position taken when the operating magnet is de-energized. The terms apply only to nonlatching types of devices.

Optoisolator A device used to connect sections of a circuit by means of a light beam.

Output Devices Elements such as solenoids, motor starters and contactors that receive input.

Overload Protection Overload protection is the result of a device which operates on excessive current, but not necessarily on short circuit, to cause and maintain the interruption of current flow to the device governed. NOTE: Operating overload means a current that is not in excess of six times the rated current for alternating-current motors, not in excess of four times the rated current for direct-current motors.

Overload Relay Running overcurrent protection; operates on excessive current; not necessarily protection for short circuit; causes and maintains interruption of device from power supply. Overload Relay Heater Coil: Coil used in thermal overload relays; provides heat to melt eutectic alloy. Overload Relay Reset: Pushbutton used to reset thermal overload relay after relay has operated.

Panelboard Panel, group of panels, or units; an assembly which mounts in a single panel; includes buses, with or without switches and/or automatic overcurrent protective devices; provides control of light, heat, power circuits; placed in or against wall or partition; accessible from front only.

Permanent-split Capacitor Motor A single-phase induction motor similar to the capacitor start motor except that it uses the same capacitance which remains in the circuit for both starting and running. (NEMA)

Permeability The ease with which a material will conduct magnetic lines of force.

Phase Relation of current to voltage at a particular time in an ac circuit. **Single Phase:** A single voltage and current in the supply. **Three Phase:** Three electrically related (120-degree electrical separation) single-phase supplies.

Phase-Failure Protection Phase-failure protection is provided by a device which operates when the power fails in one wire of a poly-phase circuit to cause and maintain the interruption of power in all the wires of the circuit.

Phase-Reversal Protection Phase-reversal protection is provided by a device which operates when the phase rotation in a poly-phase circuit reverses to cause and maintain the interruption of power in all the wires of the circuit.

Phase Rotation Relay A phase rotation relay is a relay which functions in accordance with the direction of phase rotation.

Pilot Device Directs operation of another device. **Float Switch:** A pilot device which responds to liquid levels. **Foot Switch:** A pilot device operated by the foot of an operator. **Limit Switch:** A pilot device operated by the motion of a power-driven machine; alters the electrical circuit with the machine or equipment.

Pressure Switch A pilot device operated in response to pressure levels.

Plugging Braking by reversing the line voltage or phase sequence; motor develops retarding force.

Pole The north or south magnetic end of a magnet; a terminal of a switch; one set of contacts for one circuit of main power.

Potentiometer A variable resistor with two outside fixed terminals and one terminal on the center movable arm.

Printed Circuit A board on which a predetermined pattern of printed connections has been formed.

Pull-up Torque (of alternating-current motor) The minimum torque developed by the motor during the period of acceleration from rest to the speed at which breakdown occurs. (ASA)

Pushbutton A master switch; manually operable plunger or button for an actuating device; assembled into pushbutton stations.

Rectifier A device that converts ac into dc.

Relay Operated by a change in one electrical circuit to control a device in the same circuit or another circuit; rated in amperes; used in control circuits.

Remote Control Controls the function initiation or change of an electrical device from some remote point, or location.

Remote Control Circuit Any electrical circuit which controls any other circuit through a relay or an equivalent device.

Residual Magnetism The retained or small amount of remaining magnetism in the magnetic material of an electromagnet after the current flow has stopped.

Resistance The opposition offered by a substance or body to the passage through it of an electric current; resistance converts electrical energy into heat; resistance is the reciprocal of conductance.

Resistor A device used primarily because it possesses the property of electrical resistance. A resistor is used in electrical circuits for purposes of operation, protection, or control; commonly consists of an aggregation of units.

Starting Resistors Used to accelerate a motor from rest to its normal running speed without damage to the motor and connected load from excessive currents and torques, or without drawing undesirable inrush current from the power system.

Armature Regulating Resistors Used to regulate the speed or torque of a loaded motor by resistance in the armature or power circuit.

Dynamic Braking Resistors Used to control the current and dissipate the energy when a motor is decelerated by making it act as a generator to convert its mechanical energy to electrical energy and then to heat in the resistor.

Field Discharge Resistors Used to limit the value of voltage which appears at the terminals of a motor field (or any highly inductive circuit) when the circuit is opened.

Plugging Resistors Used to control the current and torque of a motor when deceleration is forced by electrically reversing the motor while it is still running in the forward direction.

Rheostat A resistor that can be adjusted to vary its resistance without opening the circuit in which it may be connected.

Ripple An ac component in the output of a dc power supply; improper filtering.

Safety Switch Enclosed manually-operated disconnecting switch; horsepower and current rated; disconnects all power lines.

SCR Silicon controlled rectifier; a semiconductor device that must be triggered on by a pulse applied to the gate before it will conduct.

Selector Switch A master switch that is manually operated; rotating motion for actuating device; assembled into pushbutton master stations.

Semiautomatic Starter Part of the operation of this type of starter is nonautomatic while selected portions are automatically controlled.

Semiconductors See solid state devices.

Semimagnetic Control An electric controller whose functions are partly controlled by electromagnets.

Sensing Device A pilot device that measures, compares, or recognizes a change or variation in the system which it is monitoring; provides a controlled signal to operate or control other devices.

Service The conductors and equipment necessary to deliver energy from the electrical supply system to the premises served.

Service Equipment Necessary equipment, circuit breakers or switches and fuses, with accessories mounted near the entry of the electrical supply; constitutes the main control or cutoff for supply.

Service Factor (of a general-purpose motor) An allowable overload; the amount of allowable overload is indicated by a multiplier which, when applied to a normal horsepower rating, indicates the permissible loading.

Shaded Pole Motor A single-phase induction motor provided with auxiliary short-circuited winding or windings displaced in magnetic position from the main winding. (NEMA)

Slip Difference between rotor rpm and the rotating magnetic field of an ac motor.

Signal The event, phenomenon, or electrical quantity, that conveys information from one point to another.

Snubber A circuit that suppresses transient spikes.

Solenoid A tubular, current-carrying coil that provides magnetic action to perform various work functions.

Solenoid-and-plunger A solenoid-and-plunger is a solenoid provided with a bar of soft iron or steel called a plunger.

Solder Pot See Eutectic Alloy.

Solid State Devices Electronic components that control electron flow through solid materials such as crystals; e.g., transistors, diodes, integrated circuits.

Special-Purpose Motor A motor with special operating characteristics or special mechanical construction, or both, designed for a particular application and not falling within the definition of a general-purpose or definite-purpose motor. (NEMA)

Split-phase A single-phase induction motor with auxiliary winding, displaced in magnetic position from, and connected in parallel with, the main winding. (NEMA)

Starter A starter is a controller designed for accelerating a motor to normal speed in one direction of rotation. NOTE: A device designed for starting a motor in either direction of rotation includes the additional function of reversing and should be designated as a controller.

Startup The time between equipment installation and the full operation of the system.

Static Control Control system in which solid-state devices perform the functions. Refers to no moving parts or without motion.

Surge A transient variation in the current and/or potential at a point in the circuit, unwanted, temporary.

Switch A switch is a device for making, breaking, or changing the connections in an electric circuit.

Switchboard A large, single panel with a frame or assembly of panels; devices may be mounted on the face of the panels, on the back or both; contains switches, overcurrent, or protective devices; instruments accessible from the rear and front; not installed in wall-type cabinets (see Panelboard).

Synchronous Speed Motor rotor and ac rotating magnetic field in step or unison.

Tachometer Generator Used for counting revolutions per minute. Electrical magnitude or impulses are calibrated with a dial gage reading in rpm.

Temperature Relay A temperature relay is a relay which functions at a predetermined temperature in the apparatus protected. This relay is intended to protect some other apparatus such as a motor or controller and does not necessarily protect itself.

Temperature Switch A pilot device operated in response to temperature values.

Terminal A fitting attached to a circuit or device for convenience in making electrical connections.

Thermal Protector (as applied to motors) An inherent overheating protective device which is responsive to motor current and temperature. When properly applied to a motor, this device protects the motor against dangerous overheating due to overload or failure to start.

Time Limit See Definite Time.

Timer A pilot device that is also considered a timing relay; provides adjustable time period to perform function; motor driven; solenoid actuated; electronic.

Torque The torque of a motor is the twisting or turning force which tends to produce rotation.

Transducer A device that transforms power from one system to power of a second system: example, heat to electrical.

Transformer Converts voltages for use in power transmission and operation of control devices, an electromagnetic device.

Transistor An active semiconductor device which can be used for rectification and amplification by placing the proper voltage on its electrodes.

Transient See surge.

Transient Temporary voltage or current that occurs randomly and rides an ac sine wave.

Trip Free Refers to a circuit breaker which cannot be held in the on position by the handle on a sustained overload.

Troubleshoot To locate and eliminate the source of trouble in any flow of work.

Undervoltage Protection Undervoltage protection is the result when a device operates on the reduction or failure of voltage to cause and maintain the interruption of power to the main circuit.

Undervoltage Release Occurs when a device operates on the reduction or failure of voltage to cause the interruption of power to the main circuit but does not prevent the re-establishment of the main circuit on the return of voltage.

Voltage Relay A voltage relay is a relay which functions at a predetermined value of voltage. A voltage relay may be either an overvoltage or an undervoltage relay.

VOM Volt-ohm-milliammeter; a test instrument designed to measure voltage, resistance, and milliamperes.

INDEX

- AC. *See* Alternating current
- Accelerating relays, 187
- Accurate stops, motor control and, 11
- Across-the-line starting of direct current motors, 236-37
- Adjustable speed control
 - direct current controllers and, 250-56
 - installation and maintenance, 252
 - power conversion and control, 250
 - self test diagnostics, 256
 - single-phase ac and, 251-52
 - starting the motor, 250-51
 - three-phase, 253-56
- Adjustable speed controllers
 - wound rotor motors and, 207-209
 - slip power recovery and, 207-208
- Air conditioning systems
 - cooling circuit, separate control used in, 118
 - heating circuit, separate control used in, 118
 - solenoid valves and, 108-109
 - star-delta motors and, 161
- Air duct heating system, flow switch controlled, 101
- Alarm silencing circuits
 - control circuits and, 117-18
 - diagram of, 118
- Alternating current
 - adjustable frequency solid-state drives, 297-300
 - combination starters, 39-41
 - magnetic starters, 37-39
 - sizes of, 38-39
- Ambient temperature, 30
- Amortisseur windings, 213
 - out-of-step relays and, 223
- Amplifiers
 - magnetic
 - logic function and, 134
 - output function and, 134
- "And" logic element, 136
- Antiplugging circuits, 267-68
- Antiplugging protection, 267-68
- Arc deflection between contacts, 80
- Arc-quenching devices, 78
- Armature, 232-33
 - resistance, 238
- Automatic acceleration, 199-203
 - frequency relays and, 201-202
 - with reversing control, 200-201
- Automatic control, 7-10
- Automatic sequence control, 132-34
 - auxiliary contacts and, 133
 - pilot devices and, 134
- Automatic speed, wound rotor motors and, 204-206
- Automatic starters
 - star-delta motors and, 161-66
 - applications of, 161-62
 - operation of, 162-63
 - overload protection selection, 162
- Automatic starting, motor control and, 10-11
- Automatic stopping, motor control and, 10-11
- Autotransformer starters, 153-56
- Autotransformer starting, 146
- Auxiliary contact interlock, 127-28
- Auxiliary contacts, automatic sequence control and, 133
- Bimetallic overload relays, 21
 - magnetic line voltage starter and, 33-34
- Bourdon-type pressure gage, 96
- Brakes
 - electric, 270-73
 - solenoid, 270
- Braking
 - dynamic, 274-79
 - electric and electronic, 280-84
 - regenerative, 274-79
- Breakdown torque, 13
- Brushless solid-state motor excitation, 227-28
- Buttons, push, input function of, 134
- Cam switches, 58
- Capacitors
 - power factor correction, 208
 - surge, 109
 - time limit relay, 91
- Capacity proximity sensors, 104
- Centrifugal chillers, star-delta motors and, 161
- Circuits
 - alarm silencing, control circuits and, 117-18
 - antiplugging, 267-68
 - control
 - alarm silencing circuits and, 117-18
 - hand-off automatic controls and, 120-21
 - multiple push-button stations and, 123-24
 - push-to-test pilot lights and, 117
 - reversing control interlocking methods, 125-29
 - separate control and, 118-19
 - sequence control and, 132-36
 - three-wire controls and, 116-19
 - time-delay, low voltage release relay and, 137-39
 - two-wire controls and, 114-15
 - inching control, 258-61
 - jogging control, 258-61
 - maintenance, three wire control and, 54-55

- Clamps, solenoid valves and, 109
- Closed transition connections, 155
- Closed transition starting, star-delta motors and, 163-64
- Clutches
 - multiple-face, 303-304
 - single-face, 301-302
- Coils
 - magnetic blowout and, 78-79
 - mechanical interlock between, 126
- Combination push button, 69
- Compelling relays, 186-87
- Compensating time, 15
- Compensator starting, 146
- Compound motor, 233
- Compressors, synchronous motors and, 213
- Connections
 - control, 56
 - 600 volts or less, 56
 - motors, single-phase, dual voltage, 62
 - power, 56
 - 600 volts or less, 56
 - three phase motor terminal, diagrams for, 61
- Consequent pole motors
 - four speed, two winding, 186-90
 - compelling relays and, 186-87
 - operation sequence, 186
 - mistaken reversal caution, 183-84
 - reversing controls and, 184-85
 - two speed, one winding, 180-85
- Constant speed motors, 11
- Contactors
 - DC series magnetic lockout, 89
 - field, synchronous automatic motor starters and, 222
 - magnetic, 78-80
 - magnetic blowout and, 78-80
 - mechanically held, 80-82
 - sequence of operations, 80-82
 - output function and, 134
 - time delay, 90
- Contacts
 - arc deflection between, 80
 - auxiliary, automatic sequence control and, 133
 - instantaneous, 87
 - magnetic line voltage starter and, 29
 - symbols, 49
 - timed, 87
- Control
 - connections, 600 volts or less, 56
 - sequence
 - automatic, 132-34
 - auxiliary contacts and, 133
 - control circuits and, 132-36
 - defined, 132-36
 - starters wired for, 133
 - three wire, 54-56
 - maintenance circuit for, 54-55
 - no voltage protection and, 55-56
 - two wire, 54
- Control circuits, 52
 - alarm silencing circuits and, 117-18
 - diagram of, 118
 - hand-off automatic controls and, 120-21
 - diagram of, 121
 - multiple push-button stations and, 123-24
 - push-to-test pilot lights and, 117
 - reversing control interlocking methods, 125-29
 - separate control and, 118-19
 - sequence control and, 132-36
 - three-wire controls and, 116-19
 - time-delay, low-voltage release relay and, 137-39
 - construction and operation of, 138
 - two-wire controls and, 114-15
 - wiring diagram of, 115
- Control connections, 56
- Control pilot devices
 - contactors and, 78-80
 - magnetic blowout and, 78-80
 - control relays and, 74-76
 - limit switches and, 102-103
 - phase failure relays, 106-107
 - pressure switches and, 95-96
 - proximity switches, 103-105
 - push buttons and, 68-70
 - regulators and, 95-96
 - selector switches, 70-71
 - solenoid valves and, 108-110
 - solid state relays and, 76-77
 - surge protection and, 77-78
 - temperature switches and, 111-12
 - timing relays and, 84-94
 - capacitor time limit relay and, 91
 - DC series magnetic lockout contractor and, 89
 - DEC series relay and, 88
 - electronic timers and, 91-92
 - fluid dashpot, 84-85
 - instantaneous contacts and, 87
 - magnetic time limit relay and, 89-90
 - motor-driven timers and, 87-88
 - pneumatic timers, 85-87

- selection of, 92-93
- timed contacts and, 87
- timer relay selection and, 92-93
- transistors as switches, 77
- Control relays, 74-76, 75
 - jogging and, 259-60
- Control stations, 71-72
 - interlocking and, 128
 - push buttons and, 68-70
- Control systems, temperature, solid state, 111-12
- Controllers
 - AC voltage reduced, 167-74
 - adjustable speed, wound rotor motors and, 207-209
 - compensating time acceleration and, 245
 - counter emf, 245-46
 - direct current
 - across-the-line starting of, 236-37
 - adjustable speed control and, 250-56
 - compensating time acceleration, 245
 - counter emf controller, 245-46
 - definite time control starting and, 247, 249
 - field accelerating relays and, 247
 - field failure relays and, 247
 - manual faceplate starters and, 241-44
 - series starting resistance, 238-40
 - time control starting and, 245-49
 - voltage sensitive relays and, 246
 - four speed, two winding, 186-90
 - operation sequence, 186
 - magnetic, 24
 - wound rotor motors and, 196
 - motor control installation considerations and, 3
 - motor, interlocking and, 128
 - programmable, 310-14
 - input module for, 312-13
 - installation of, 314
 - output module for, 313
 - power supply for, 312
 - processor unit for, 313
 - purpose of, 4-6
 - damage protection, 5
 - maintenance of starting requirements, 5-6
 - operator safety, 5
 - reversing, 5
 - running, 5
 - speed control, 5
 - starting, 4-5
 - stopping, 5
 - tasks of, 3
 - two speed, one winding, 180-85
 - mistaken reversal caution, 183-84
 - reversing controls and, 184-85
 - two speed, two winding, 176-79
- Controls
 - hand-off automatic, control circuits and, 120-21
 - three-wire
 - control circuits and, 116-19
 - start-stop stations and, 116
 - two-wire, control circuits and, 114-15
- Counter emf, 238
 - emf controller, 245-46
- Cranes, varying speed motors and, 11
- Current
 - limiting acceleration, 15
 - starting, motors and, 145-46
 - torque and, 145
 - torque curves, 90
- Cylindrical shaped proximity switches, 105
- Damage protection, controllers and, 5
- Dashpot fluid, silicone, 85
- Dashpot timing relays, fluid, 84-85
- DC. *See* Direct current
- Decelerating relays, 187
- Deceleration
 - dynamic braking, 274-79
 - electric and electronic braking and, 280-84
 - electric brakes, 270-73
 - jogging control circuits and, 258-61
 - plugging and, 262-69
 - regenerative braking, 274-79
- Definite time control starting, 247, 249
- Definite time relays, 15
- Diagrams
 - drum switch, 57-58
 - selector switch, 56-57
 - wiring, converted from an elementary diagram, 62-63
- Diodes, light emitting, 104
- Direct current controllers
 - across-the-line starting of, 236-37
 - adjustable speed control and, 250-56
 - installation and maintenance, 252
 - power conversion and control, 250
 - self test diagnostics, 256
 - single-phase ac and, 251-52
 - starting the motor, 250-51
 - three-phase, 253-56
 - compensating time acceleration, 245
 - counter emf controller, 245-46
 - definite time control starting and, 247-49

- Direct current controllers (cont'd)
 - field accelerating relays and, 247
 - field failure relays and, 247
 - manual faceplate starters and, 241-44
 - series starting resistance, 238-40
 - time control starting and, 245-49
 - voltage sensitive relays and, 246
- Direct current motors, 232-35
 - application of, 232
 - construction of, 232-33
 - armature, 232-33
 - field, 232
 - motor rotation, 234
 - speed control, 234
 - starting of, 235
 - types of, 233
- Direct current, series magnetic lockout contactor, 89
- Direct current series relay, 88
- Direct current variable speed control, 306-309
- Direct motor drives, 286-90
- Disc brakes, magnetic, 271
- Drum controller, 6
- Drum switch
 - defined, 57
 - diagram, 57-58
- Dynamic braking, 274-79
- Eddy currents, 26-27
- Electric brakes, 270-73
- Electric braking, 280-84
 - application of, 280
 - circuit sequence and operation of, 282-83
 - construction of, 281
 - operation of, 281
 - wound-rotor motor and, 283-84
- Electric circuits, diagrams for, 51-54
- Electric service, motor control installation considerations and, 2
- Electrical codes and standards, motor control installation considerations and, 4
- Electrical interlock, 9-10
 - diagram of, 128
- Electrical interlock. *See also* Push-button interlock
- Electrical sequence control, 9-10
- Electromagnetic
 - operated switches, 78-80
 - magnetic blowout and, 78-80
 - timers, selection of, 92-93
- Electromagnets
 - mechanically held contactor and, 80-82
 - sequence of operations, 80-82
 - mechanically held relays and, 80-82
 - sequence of operations, 80-82
 - starter, 24-27
- Electron tubes, logic function and, 134
- Electronic braking, 280-84
 - application of, 280
 - circuit sequence and operation of, 282-83
 - construction of, 281
 - operation of, 281
 - wound-rotor motor and, 283-84
- Electronic contactors, output function and, 134
- Electronic control starting, 147
- Electronic timers, 91-92
- Elementary diagrams, wiring diagrams converted to, 62-63
- Enclosures
 - protective, 39-41
 - push button, 69
- Environment, motor control installation considerations and, 3-4
- Faceplate control, 6
- Faceplate starters, 241-44
- Fans, synchronous motors and, 213
- Field accelerating relays, 247
- Field contactor, synchronous automatic motor starters and, 222
- Field failure relay, 247
- Field rheostat, 243
- Fleming's left hand rule, 79
- Float switches, 8, 97-98
 - control circuit for, 98
- Flow switches, 99-101
 - air duct heating systems and, 101
 - diagrams of, 100
- Fluid dashpot timing devices, 84-85
- Fluid, silicone dashpot, 85
- Four-point resistor starter, 150-51
- Four-way solenoid valves, 109
- Fractional horsepower motor starters, 17-20, 21-22
- Freon, solenoid valves and, 108-109
- Frequency relays, automatic acceleration and, 201-202
- Friction brakes, 270-273
- Full voltage starting, 146
- Gear motors, motor drives and, 291-93
- Hand-off automatic controls
 - control circuits and, 120-21
 - diagram of, 121

- Heating systems, air duct, flow switch controlled, 101
- Heavy duty starting, motor control and, 10
- Hoists, varying speed motors and, 11
- Horsepower
 - fractional, manual motor starters and, 17-20, 21-22
 - integral, manual motor starters and, 20-22
- Hydraulic pumps, sequence control and, 132-34
- Hydraulic valves, logic function and, 134
- Impedance starting, 146
- Inching control circuits, 258-61
- Inching, defined, 258
- Inductive proximity sensors, 104
- Input function, 134
- Instantaneous contacts, 87
- Instantaneous trip current relays, magnetic line voltage starter and, 35-36
- Integral horsepower motor starters, 20-22
- Interlock
 - electrical, 9-10
 - mechanical, 9-10
- Interlocking
 - defined, 125
 - methods of, 126-28
 - auxiliary contact, 127-28
 - mechanical, 126
 - push-button, 127
- Jig clamps, solenoid valves and, 109
- Jogging
 - control relay and, 259-60
 - defined, 258
 - reversing starter and, 260
 - selector switches and, 260-61
- Jogging control circuits, 258-61
- LED. *See* Light emitting diodes
- Light duty starting, motor control and, 10
- Light emitting diodes, 104
- Lights, pilot, push-to-test, 117
- Limit switches, 9
 - control pilot devices and, 102-103
 - input function of, 134
- Line diagrams, 51-54
 - defined, 51-52
- Line frequency currents, 225
- Locked rotor, 30
- Lockout-on-stop push button, 72
- Logic element
 - "and", 136
 - "or", 136
 - Logic function, 134
 - Low-voltage release relay, 137-39
 - diagram of, 138
- Machine clamps, solenoid valves and, 109
- Magnet coil, magnetic line voltage starters and, 28-29
- Magnetic amplifiers
 - logic function and, 134
 - output function and, 134
- Magnetic blowout
 - coils, 78-79
 - magnetic contactors and, 78-80
- Magnetic brakes, 270-73
 - direct current, 271-72
 - disc, 271
- Magnetic clutches, motor drives and, 301-304
- Magnetic contactors, 78-80
 - magnetic blowout and, 78-80
- Magnetic controllers, 24
 - wound rotor motors and, 196
- Magnetic devices, solid-state control with, 170-73
- Magnetic drives, 304-305
- Magnetic line voltage starters, 24-43
 - AC, 37-39
 - AC combination, 39-41
 - contacts and, 29
 - magnet coil and, 28-29
 - motor overheat and, 30-37
 - bimetallic overload relays and, 33-34
 - instantaneous trip current relays and, 35-36
 - overload relays needed for, 36-37
 - protection from, 32-33
 - time limit overload relays and, 35
 - power circuit of, 29
 - shaded pole principle and, 27-28
 - versus manual, 24
- Magnetic overload relay, 84
- Magnetic relays, 74
 - overload protection and, 74-75
 - solid state devices and, 77
 - transient suppressor installed on, 78
- Magnetic switch control, 7
- Magnetic switches, two-wire controls and, 114
- Magnetic time limit relay, 89-90
- Maintenance circuit, three wire control and, 54-55
- Manual control
 - defined, 6
 - drum controller, 6
 - faceplate control, 6

Manual control (cont'd)

- safety switch, 6
- toggle switch, 6

Manual faceplate starters, 241-44

Manual speed control, wound rotor motors and, 192-95

Manual starters

- fractional horsepower and, 17-20, 21-22
- integral horsepower and, 20-22
- low voltage protection, 20-21

Manual starting, motor control and, 10-11

Manual stopping, motor control and, 10-11

Mechanical brakes, 270-73

Mechanical interlock, 9-10, 126

Mechanical protection, 14

Mechanical sequence control, 9-10

Metal alloy thermal units, 32-33

Methyl chloride, solenoid valves and, 108-109

Motor control

- accurate stops, 11
- automatic, 7-10
- controller and, 4-6
 - damage protection, 5
 - maintenance of starting requirements, 5-6
 - operator safety, 5
 - reversing, 5
 - running, 5
 - speed control, 5
 - starting, 4-5
 - stopping, 5
- defined, 2

installation considerations, 2-4

- controller operating characteristics, 3
- electric service, 2
- electrical codes and standards and, 4
- environment and, 3-4
- motor, 2-3

manual control and, 6

mechanical protection, 14

overspeed protection, 14

overtravel protection, 14

protective features, 13-14

open field protection, 13

open-phase protection, 13

overload protection, 13

quick or slow control, 11

remote, 7-10

reversals, frequency of, 11

reverse current protection, 14

reverse phase protection, 14

short circuit protection, 14

starting and stopping, 10-11

starting systems, classification of automatic, 14-15

Motor control center, 317

Motor controllers, interlocking and, 128

Motor current monitor, 107

Motor driven timers, 87-88

Motor drives

AC adjustable frequency solid-state drives, 297-300

DC variable speed control and, 306-309

direct drives and, 286-90gear motors and, 291-93

loads and, 322

magnetic clutches and, 301-304

magnetic drives and, 304-305

motion control and, 318

motor startup and, 320

programmable controllers and, 310-13

pulley drives and, 288-90

stepper motors and, 318-19

trouble shooting and, 322-29

variable frequency mechanical drives, 294-96

Motor excitation, brushless, 227-28

Motor mounts, 321

Motor overheat

magnetic line voltage starter and, 30-37

bimetallic overload relays and, 33-34

instantaneous trip current relays and, 35-36

magnetic overload relays and, 34-35

overload relays needed for, 36-37

protection from, 32-33

time limit overload relays and, 35

Motor starters

integral, horsepower and, 20-22

manual, fractional horsepower and, 17-20, 21-22

Motor startup, motor drives and, 320

Motors

compound, 233

connections

single-phase, dual voltage, 62

three-phase, dual voltage, 60-62

consequent, four speed, two winding, 186-90

consequent pole, 180-85

direct current, 232-35

application of, 232

construction of, 232-33

motor rotation, 234

starting of, 235

types of, 233

gear, motor drives and, 291-93

induction at start, 143

locked rotor currents and, 143

- motor control installation considerations and, 2-3
 - nameplate data and, 58-60
 - overload protection, 31-32
 - magnetic relays and, 74-75
 - part winding starters and, 157-60
 - pump, float switches and, 97-98
 - revolving field and, 142-43
 - series, 233
 - shunt, 233
 - slip ring, manual speed control and, 192-95
 - speed control of, 11, 13, 234
 - squirrel cage, 142-47
 - controlling torque, 145
 - induction motor at start and, 143
 - locked rotor currents and, 143
 - no-load speed rotors and, 144
 - one winding controllers and, 180-85
 - part winding starters and, 157-60
 - primary resistor starters and, 148
 - revolving field and, 142-43
 - starting current and, 145-46
 - torque, variation of requirements of, 144-45
 - star-delta, automatic starters for, 161-66
 - starting current and, 145-46
 - stepper, motor drives and, 318-19
 - synchronous
 - automatic motor starters and, 222-28
 - brushless excitation, 227-28
 - dynamic braking and, 277-78
 - operation of, 212-16
 - power factor correction by, 214-15
 - push-button synchronizing and, 217-19
 - synchronous automatic motor starters and, 222-28
 - three phase terminal connections, diagrams for, 61
 - torque
 - controlling, 145
 - variation of requirements of, 144-45
 - voltage starters and, 142-46
 - wound rotor
 - adjustable speed controller for, 207-209
 - automatic acceleration and, 199-203
 - automatic speed, 204-206
 - manual speed control and, 192-95
 - push-button speed selection and, 196-98
- Multiple-face clutches, 303-304**
- Nameplates**
- motor drives and, 321-22
 - motors and, 58-60
 - samples, 60
- National Electrical Code, 4
 - nameplate data and, 58
 - National Electrical Manufacturers Association, 4
 - No-load speed rotors, 144
 - No-voltage protection arrangement, 117
- Occupational Safety and Health Act, 4
 - Ohm's law, 238
 - Oil dashpot timing relays, 84
 - Open field protection, 13
 - Open-phase protection, 13
 - Open push button unit, 70
 - Open selector switches, 70
 - Operator safety, controllers and, 5
 - "Or" logic element, 136
 - OSHA, 4
 - Out-of-step relays, synchronous automatic motor starters and, 223
 - Output function, 134
 - Overload protection, 13
 - part winding motor starters and, 160
 - Overload relays, magnetic line voltage starter and, 36-37
 - Overspeed protection, 14
 - Overtravel protection, 14
- Palm operated push buttons, 69
 - Pancake-type solid state sensors, 105
 - Part winding motor starters, 157-60
 - diagram of, 159
 - overload protection and, 160
 - Part winding starting, 147
 - Phase failure relays, control pilot devices and, 106-107
 - Phase reversal, 106
 - polyphase torque and, 106-107
 - Photocells, input function of, 134
 - Pilot devices, automatic sequence control and, 134
 - Pilot lights, push-to-test, 117
 - Pipe, flow switches and, 99-101
 - Plugging
 - deceleration and, 262-69
 - defined, 262
 - time relay and, 264-65
 - Plugging switches, 262-64
 - alternate circuits for, 265-67
 - Pneumatic cylinders, solenoid valves and, 109
 - Pneumatic timers, 85-87
 - Pneumatic valves, logic function and, 134
 - Polarized field frequency relays
 - operation of, 224
 - synchronous automatic motor starters and, 223-27

- Polarized field frequency relays (cont'd)
 - synchronous motor and, 226
 - wiring connections and, 225
- Polyphase torque, phase reversal and, 106-107
- Power circuit, 52
 - diagram for, 170
- Power connections, 56
 - 600 volts or less, 56
- Power factor correction,
 - capacitors, 208
 - synchronous motors and, 214-15
- Power supply, transient overloading of, 146
- Press clutches, solenoid valves and, 109
- Pressure regulators, 96
- Pressure switches, 8, 95-96
 - diagram of, 96
 - input function of, 134
- Primary resistance starters, 146
 - features of, 151
- Primary resistor starters, 148-52
 - diagram of, 150
- Production lines, proximity switches and, 105
- Programmable controllers, 310-14
 - input module for, 312-13
 - installation of, 314
 - output module for, 313
 - power supply for, 312
 - processor unit for, 313
- Programmable terminal, 314-17
- Protective enclosures, 39-41
- Proximity switches
 - application of, 105
 - capacity, 104
 - control pilot devices and, 103-105
 - cylindrical, 105
 - input function of, 134
- Pulley motor drives, 288-90
- Pump motors, float switches and, 97-98
- Pumps, synchronous motors and, 213
- Push-button interlock, 127
 - diagram of, 178
- Push-button speed selection, 196-98
- Push-button stations, multiple, control circuits and, 123-24
- Push-button synchronizing, 217-19
 - diagram of, 218
- Push buttons, 68-70
 - combination, 69
 - input function of, 134
 - mechanical lockout-on-stop, 72
 - palm operated, 69
 - stations, 69
- Push-to-test pilot lights, 117
- Quick start, motor control and, 11
- Refrigeration systems, solenoid valves and, 108-109
- Refrigerators, flow switches and, 101
- Regenerative braking, 274-79
- Regulators, 95-96
 - pressure, 96
- Relays
 - accelerating, 187
 - bimetallic, 21
 - overload, magnetic line voltage starter and, 33-34
 - capacitor time limit, 91
 - compelling, 186-87
 - control, 74-76, 75
 - jogging and, 259-60
 - decelerating, 187
 - definite time, 15
 - direct current series, 88
 - field accelerating, 247
 - field failure, 247
 - frequency, automatic acceleration and, 201-202
 - instantaneous trip current, magnetic line voltage starter and, 35-36
 - logic function and, 134
 - magnetic
 - overload, 84
 - overload protection and, 74-75
 - solid state devices and, 77
 - time limit, 89-90
 - transient suppressor installed on, 78
 - mechanically held, 80-82
 - sequence of operations, 80-82
 - out-of-step, synchronous automatic motor starters and, 223
 - overload, 36-37
 - phase failure, control pilot devices and, 106-107
 - polarized field frequency
 - operation of, 224
 - synchronous automatic motor starters and, 223-27
 - wiring connections and, 225
 - release, time-delay, low voltage, 137-39
 - solder-pot, 21
 - solid state, 76-77
 - thermostat, 82
 - time limit overload, magnetic line voltage starter and, 35
 - time, plugging and, 264-65
 - timing, 84-94

- fluid dashpot, 84-85
 - selection of, 92-93
- voltage sensitive, 246
- Remote control, 7-10
- Resistance starters
 - primary, 148
 - features of, 151
- Resistor starter, four-point, 150-51
- Reversals, frequency of, motor control and, 11
- Reverse current protection, 14
- Reverse phase protection, 14
- Reversing control interlocking methods, control circuits and, 125-29
- Reversing, controllers and, 5
- Reversing controls, 184-87
- Reversing starters
 - diagram of, 127
 - jogging and, 260
 - power circuit, diagram of, 126
- Rheostat, field, 243
- Rotating magnetic field, formula for, 176
- Rotors
 - control equipment, synchronous automatic motor starters and, 222-27
 - defined, 142
 - locked currents, 143
 - no-load speed, 144
 - slip and, 144
 - wound, 192-193
- Running, controllers and, 5
- Running protection. *See* Overload protection
- Safety, operator, controllers and, 5
- Safety switch, 6
- Selector switches, 70-71
 - diagramming, 56-57
 - jogging and, 260-61
- Sensors
 - capacity proximity, 104
 - inductive proximity, 104
 - pancake-type, 105
- Separate winding motors, controllers for, 176-79
- Sequence control
 - automatic, 132-34
 - auxiliary contacts and, 133
 - pilot devices and, 134
 - control circuits and, 132-36
 - defined, 132-36
 - electrical, 9-10
 - mechanical, 9-10
 - starters wired for, 133
- Sequence tables. *See* Target tables
- Series motor, 233
- Series-wound brakes, 271
- Shaded pole principle, 27-28
- Short circuit protection, 14
- Shunt motor, 233
- Shunt-wound brakes, 271
- Silicon controlled rectifiers, 168
 - direct current motors and, 234
 - outputs from differently gated, 169
 - power circuit for, 170
- Silicone dashpot fluid, 85
- Single-face clutch, 301
- Single phase torque, 107
- Slip, defined, 144
- Slip power recovery, 207-208
 - power factor correction capacitors, 208
- Slip ring motors, manual speed control and, 192-95
- Slow start, motor control and, 11
- Solder-pot overload relays, 21
- Solenoid, 25
- Solenoid brake, 270
- Solenoid valves
 - control pilot devices and, 108-110
 - defined, 108
 - four-way, 109
 - output function and, 134
 - two-way, 108-109
- Solid-state adjustable speed controllers, wound rotor motors and, 207-209
- Solid-state contactors, output function and, 134
- Solid-state control,
 - magnetic devices and, 170-73
 - control, need for, 167-68
- Solid-state defined, 167
- Solid-state devices
 - advantages of, 77
 - surge protection and, 77
- Solid-state electronic control starting, 147
- Solid-state logic element
 - "and", 135
 - "or", 136
- Solid-state proximity switches, 103-105
- Solid-state reduced voltage starting, 168-70
- Solid-state relays, 76-77
- Solid-state switching, 77
- Solid-state temperature control systems, 111-12
- Solid-state timers,
 - diagram for, 92

- Solid-state timers (cont'd)
 - selection of, 92-93
- Speed control
 - adjustable, direct current controllers and, 250-56
 - automatic, wound rotor motors and, 204-206
 - controllers and, 5
 - direct current variable, 306-309
 - manual, wound rotor motors and, 192-95
- Speed controllers, adjustable, wound rotor motors and, 207-209
- Speed selection
 - automatic acceleration, 199-203
 - frequency relays and, 201-202
 - with reversing control, 200-201
 - push-button, 196-98
- Spot welders, solenoid valves and, 109
- Squirrel cage motors, 142-47
 - no-load speed rotors and, 144
 - part winding starters and, 157-60
 - primary resistor starters and, 148
 - revolving field and, 142-43
 - starting current and, 145-46
 - three phase, one winding controllers and, 180-85
 - torque
 - controlling, 145
 - variation of requirements of, 144-45
- Star-delta motors
 - automatic starters and
 - applications of, 161-62
 - operation of, 162-63
 - overload protection selection, 162
 - automatic starters for, 161-66
 - closed transition starting and, 163-64
- Star-delta starters, diagram of, 163, 164
- Star-delta starting, 147
- Starter, electromagnets, 24-27
- Starters
 - AC reduced voltage
 - autotransformer starters and, 153-56
 - motors and, 142-46
 - part winding motor starters and, 157-60
 - star-delta motors and, 161-66
 - starting methods, 142-46
 - AC voltage reduced, voltage controllers and, 167-74
 - automatic, star-delta motors and, 161-66
 - autotransformer, 153-56
 - line diagram of, 53
 - magnetic line, AC combination, 39-41
 - magnetic line voltage, 24-43
 - contacts and, 29
 - magnet coil and, 28-29
 - motor overheat and, 30-37
 - power circuit of, 29
 - shaded pole principle and, 27-28
 - magnetic versus manual, 24
 - magnetic voltage line, AC, 37-39
 - manual
 - fractional horsepower and, 17-20, 21-22
 - integral horsepower and, 20-22
 - manual faceplate, 241-44
 - output function and, 134
 - part winding motor, 157-60
 - diagram of, 159
 - overload protection and, 160
 - primary resistance, 148
 - features of, 151
 - primary resistor-type, 148-52
 - pump motor, float switches and, 97
 - resistor, four-point, 150-51
 - reversing, 126
 - diagram of, 127
 - jogging and, 260
 - power circuit for, 126
 - sizes of, 38
 - star-delta, diagram of, 163, 164
 - synchronous automatic motor, 222-28
 - three wire control and, 54-56
 - maintenance circuit for, 54-55
 - voltage protection and, 55-56
 - two wire control of, 54
 - voltage, manual push-button line, 20-21
 - wired for sequence control, 133
- Starting
 - autotransformer, 146
 - compensator, 146
 - definite time control, 247-49
 - fast or slow, motor control and, 10
 - frequency of, motor control and, 10
 - full voltage, 146
 - heavy or light duty, motor control and, 10
 - impedance, 146
 - part winding, 147
 - primary resistance, 146
 - requirements, maintenance of, 5-6
 - smooth, motor control and, 10
 - solid-state electronic control, 147
 - solid-state reduced voltage, 168-70
 - star-delta, 147
 - three-step, 159-60
 - two-step, 158-59
- Starting compensators. *See* Autotransformers
- Start-stop stations, three-wire control circuits and, 116

- Static control. *See* Solid-state
- Stations, control, interlocking and, 128
- Stator, 142
 - flat, 180
- Stepper motors, motor drives and, 318-19
- Stopping
 - controllers and, 5
 - frequency of, motor control and, 10
 - manual or automatic, 10-11
- Sulphur dioxide, solenoid valves and, 108-109
- Surge capacitors, 109
- Surge protection, 77-78
- Surge suppressors, 171
- Switches
 - cam, 58
 - drum, diagramming of, 57-58
 - electromagnetically operated, 78-80
 - magnetic blowout and, 78-80
 - float, 8, 97-98
 - control circuit for, 98
 - flow, 99-101
 - air duct heating systems and, 101
 - diagrams of, 100
 - limit, 9
 - control pilot devices and, 102-103
 - input function of, 134
 - magnetic, two-wire controls and, 114
 - open selector, 70
 - plugging, 262-64
 - alternate circuits for, 265-67
 - pressure, 8, 95-96
 - diagram of, 96
 - input function of, 134
 - proximity
 - application of, 105
 - capacity, 104
 - control pilot devices and, 103-105
 - cylindrical shaped, 105
 - input function of, 134
 - safety, 6
 - selector, 70-71
 - diagramming of, 56-57
 - jogging and, 260-61
 - temperature, control pilot devices and, 111-12
 - toggle, 6
 - transistors as, 77
 - zero-speed, 262-64
- Symbols, 46-50
 - wiring diagram, 46-47
- Synchronous automatic motor starters, 222-28
 - rotor control equipment and, 222-27
- Synchronous motor control, functions of, 217
- Synchronous motors
 - brushless excitation, 227-28
 - dynamic braking and, 277-78
 - operation of, 212-16
 - power factor correction by, 214-15
 - push-button synchronizing and, 217-19
 - diagram of, 218
 - synchronous automatic motor starters and, 222-28
 - timed semiautomatic synchronizing and, 220-21
 - uses of, 213
- Target tables, 56
- Temperature control systems, solid state, 111-12
- Temperature switches, control pilot devices and, 111-12
- Terminals, programmable, 314-17
- Thermal overload protection, 21-22
- Thermal units, metal alloy, 32-33
- Thermostat, 8-9
- Thermostat relay, 82
- Thermostats, 111
- Three-step starting, 159-60
- Three wire controls, 54-56
 - control circuits and, 116-19
 - maintenance circuit for, 54-55
 - no voltage protection and, 55-56
 - start-stop stations and, 116
- Time clock, 8
- Time delay,
 - acceleration, 15
 - contactor, 90
 - low voltage release relay, 137-39
 - construction and operation of, 138
- Time limit overload relays, magnetic line voltage starter and, 35
- Time limit relay, capacitor, 91
- Time relays, plugging and, 264-65
- Timed contacts, 87
- Timers
 - electromagnetic, selection of, 92-93
 - electronic, 91-92
 - motor driven, 87-88
 - pneumatic, 85-87
 - solid state
 - diagram for, 92
 - selection of, 92-93
- Timing relays, 84-94
 - fluid dashpot, 84-85
 - selection of, 92-93
 - allowable error and, 92
 - cost and, 93

Timing relays (cont'd)

- cycle of operation required, 92-93
- reset time and, 92-93
- time delay required and, 92
- timing range required, 92

Toggle switch, 6

Torque

- controlling, 145
- curves, current, 90
- defined, 144
- polyphase, phase reversal and, 106-107
- reduced current and, 145
- reduced voltage and, 145
- single phase, 107
- variation of requirements of, 144-45

Transient suppressor, 77

- magnetic relay and, 78

Transistors

- logic function and, 134
- as switches, 77

Trouble shooting guide, 322-29

Tubes, electron, logic function and, 134

Turret lathes, multispeed motors and, 13

Two wire control, 54

Two-speed, two-winding motors. *See* Separate winding motors

Two-step starting, 158-59

Two-way solenoid valves, 108-109

Two-wire controls

- control circuits and, 114-15
- wiring diagram of, 115
- magnetic switches and, 114

Underwriter's Laboratories, 4

Valves

- hydraulic, logic function and, 134
- pneumatic, logic function and, 134
- solenoid
 - control pilot devices and, 108-110
 - defined, 108
 - four-way, 109
 - output function and, 134

two-way, 108-109

Variable frequency mechanical drives, 294-96

Voltage

- regulation, 146
- surge suppressor, 171
- torque and, 145

Voltage protection, three wire control and, 55-56

Voltage sensitive relays, 246

Voltage starters

AC reduced

- autotransformer starters and, 153-56
- motors and, 142-46
- part winding motor starters and, 157-60
- primary resistor-type starters, 148-52
- star-delta motors and, 161-66
- starting methods, 146-47
- voltage controllers and, 167-74
- manual push-button line, 20-21

Water pumps, constant speed motors and, 11

Winding starters, 157-60

Windings, amortisseur, 213

Wiring diagrams, 51-54

- converting to an elementary diagram, 62-63
- defined, 51
- symbols, 46-47

Wiring, interpretation, 58-60

Wound rotor motors

adjustable speed controller for, 207-209

automatic acceleration and, 199-203

frequency relays and, 201-202

with reversing control, 200-201

automatic speed, 204-206

automatic speed control and

diagram of, 205

slip power recovery and, 207-208

electric braking and, 283-84

manual speed control and, 192-95

push-button speed selection and, 196-98

Wound rotors, 192-93

Wye-delta starter, 164

Zero-speed switches, 262-64

OUTSTANDING RELATED DELMAR TITLES

- ☐ **Electrical Grounding, O'Riley**
- ☐ **Electrical Control for Machines, 3rd Ed., Rexford**
- ☐ **Industrial Motor Control, Herman & Alerich**
- ☐ **Alternating Current Fundamentals, 3rd Ed., Duff & Herman**
- ☐ **Direct Current Fundamentals, 3rd Ed., Loper & Tedsen**



Delmar Publishers Inc.

ISBN: 0-8273-3039-1